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Journal
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Devoted to Science and the Mechanic Arts

Vol. 198 JULY, 1924 No. 1

COMPRESSIBILITY, INTERNAL PRESSURE AND CHANGE OF ATOMIC VOLUME.*

BY

THEODORE WILLIAM RICHARDS, Ph.D., Sc.D., Chem.D., M.D., LL.D.

Director, Wolcott Gibbs Memorial Laboratory, Harvard University; Franklin Medallist, Member of the Institute.

SPECULATION concerning the ultimate nature of things began long ago. The ancient philosophers attempted not only to envisage the nature of matter itself, but also the relation of mind to matter. From a philosophical point of view, these considerations are, indeed, inextricably entwined. Nevertheless, fortunately this afternoon we are not concerned with the philosophical question as to whether our visible and tangible world is subjective or objective. For our present purpose the definite verdict of our senses may be accepted as representing realities, insofar as anything may be called real.

Scientific experiment and thought have led to the formulation of the two fundamental concepts of "energy" and "matter"—the latter being conceived as a localized bundle of energies. The marvellous behavior of these two agencies, which together weave the pattern of the visible and tangible universe, has been studied and appraised by the yet more marvellous action of the human mind—chiefly during the last four hundred years.

* Presented at the Stated Meeting of the Institute held Wednesday, April 16, 1924.

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I come to-day, however, not to talk about metaphysical questions, but rather to present to you some of the outcomes of recent investigations concerning certain definite relations of matter and energy which seem to me to possess a significance and interest not generally perceived. These investigations concern the magnitude and nature of the effects of *pressure* on matter, and the bearing of these effects on our interpretation of the nature of things.

Everyone appreciates the fact that pressure has important effect on the bulk of matter, whether solid, liquid or gaseous. Increase of external pressure, pressing inward, always tends to diminish the volume of any substance or system to which it is applied. Pressures therefore are usually determined by observing change of volume. The object of the first part of the present argument is to extend this mode of inferring pressures from the physical to the chemical domain.

In order to make the argument as clear as possible, let us study a single case in which change of volume occurs in a chemical reaction, and then step by step endeavor to find out whether or not we have a right to conclude that this change of volume is due, as in physical phenomena it is usually due, to change of pressure.

When potassium combines with chlorine to make potassium chloride, the light, soft metal potassium and the heavy, greenish-yellow, liquefied chlorine both apparently disappear to produce a colorless salt very like common salt; and a contraction of 33 cubic centimetres occurs for every gram-molecule of compound, since the factors in the reaction occupied 70.5, and the products only 37.5 cubic centimetres. The great contraction, which serves as an example of many such cases, presents a puzzle, the solution of which I hope partially to present to-day.

The study of physics tells us, as has been said, that changes of volume are usually due to changes of pressure. If we could prove that this connection always exists, to the exclusion of any other cause of change of volume, we could at once declare positively that the contraction described above must be due to pressure—to some sort of internal pressure between the atoms, not obvious on the surface. Although this premise cannot be established with absolute certainty, nevertheless changes of volume are so usually caused by changes of pressure that one is authorized in accepting the conclusion just stated as a working hypothesis.

Let us then ask the question: What kind of internal pressure

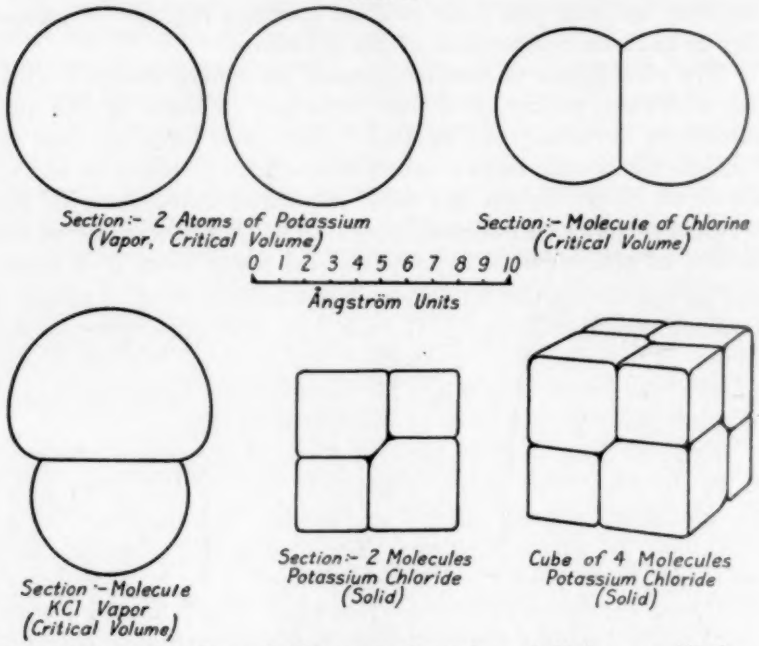
would be likely to cause such an effect as that under discussion? Obviously the most likely cause of the pressure is the great chemical affinity which is known to exist between the atoms of potassium and the atoms of chlorine. These two substances combine with a brilliant flame and the evolution of much heat. They show every evidence of a great chemical attraction for one another. Is it not likely that this attraction would not only *bind* the substances together, but also *pull* their smallest particles together in such a way as to cause compression of the substance?

The mechanism of the compression we cannot conceive without a definite picture as to the structure of each of the two substances attracting one another. This need leads us, then, to consider the atomic theory, which seems both to chemists and to physicists to-day by far the most reasonable explanation of the outward behavior of material things. The theory was one of the earliest of philosophical hypotheses. In vague form it is found as a part of the Vaiśēshika philosophy of ancient India. Leucippus and Democritus, before the Golden Age of Greece, held similar views. Lucretius later crystallized the ancient, but unproved, tenets of the atomic theory into his extraordinary hexameters, thus in poetic guise giving form to the ancient dream.

None of these thinkers brought forward adequate evidence to prove his case, and strong arguments lay on the other side; the philosophers made merely a plausible, if somewhat vague, guess as to the nature of things. Their guess was unquestionably the sketch from which the elaborate picture of the modern chemical atomic theory was evolved. Not much over a hundred years ago Dalton brought forward convincing quantitative chemical evidence in favor of a chemical atomic theory, thus putting it upon a firm basis. Later it was adopted by physicists to explain the pressure of gases. To-day the arguments in favor of the idea that all elementary matter is made up of definite very small particles, or "atoms" (which combine to make the molecules of compounds, but which remain intact during all ordinary chemical changes), is so overwhelming that no one is inclined to dispute it. Very recently we have evidence that these particles are not absolutely indestructible, if subjected to sufficient stress; but this evidence does not affect the main argument in the least. The atomic theory, then, may be assumed as the best basis for the explanation of the phenomena before us.

But how can the chemical affinity cause a diminution in the size of these atoms? The ancients conceived that the atoms must be, as Newton put it, "hard, massy particles," so hard that they could never be worn out. This notion persists, often subconsciously, in the minds of many people to-day. It seems to me that the example before us goes far to refute this notion. We may

FIG. 1.



Probable changes of volume suffered by atoms of potassium and chlorine on combination. Magnified 35 million diameters.

imagine that chlorine combines with potassium somewhat after the fashion drawn to scale in the accompanying diagram. (Fig. 1.) The mutually attracting atoms of chlorine and potassium may be imagined to compress one another, somewhat in the way shown in the lower left-hand corner of the diagram, making a single molecule of potassium chloride. When these molecules are combined together to make a solid crystal, something like the arrangement shown in the lower right-hand corner may be formed. An alternative conception postulates that the centres instead of the edges of the structure are arranged cubically; either conception serves the present purpose.

This picture does not make any attempt to decide how the so-called " substance " of the atom is arranged in the space allotted to each. It merely postulates the existence of some sort of repelling tendency which prevents the centres of the atoms from coming into contact. The great force which unquestionably holds them together must be met by a repelling tendency, which balances the attracting tendency. When the latter grows greater the atoms approach more closely. One need not assume any definite shell; indeed, probably, no such shell exists. The present consensus of opinion of physicists is that the atom consists of a positively charged nucleus with negative electrons disposed in some fashion around it. Such a structure might well behave in precisely the method graphically represented by this diagram.

If, as a matter of fact, chemical affinity is responsible for the change of volume, and if this change of volume is really a compression caused by increasing pressure, we should find that where great affinities are concerned the compression should be great, but where small affinities are concerned, the compression should be small. We have no certain method of measuring such pressures as might be produced by chemical affinity, but we can guess that they are usually great when the heat of reaction is great and small when the heat of reaction is small. Hence there should be some sort of parallelism between heat of reaction and contraction on combination. Such a parallelism seems indeed to exist. Table I shows the contraction which occurs when a feebly bound compound of potassium and sodium, evolving little heat, is formed, compared with a contraction which occurs when the firmly bound compound common salt, evolving much heat, is formed.

TABLE I.

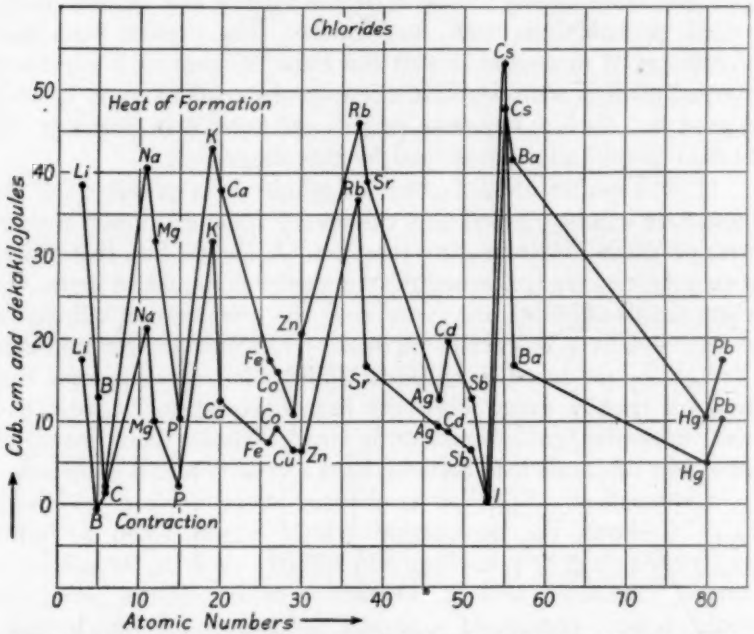
	Contraction on Combination.	Heat of Formation.
Na + K	0.9	5.
Na + Br	15.1	359.

This case is given not as proof, but as an example. Of course a single case proves very little. Let us compare many reactions, so as to be on safer ground. The next diagram shows graphically a comparison of the contraction on combination with the heats of reaction of a number of chlorides plotted side by side

after the fashion of graphs of security and commodity prices which one sees in the daily papers. (Fig. 2.) There can be no doubt of the parallelism. The argument is strong that great affinity is associated with great contraction.

The first person to draw attention to facts of this kind was perhaps Sir Humphry Davy, who seems also to have guessed that

FIG. 2.

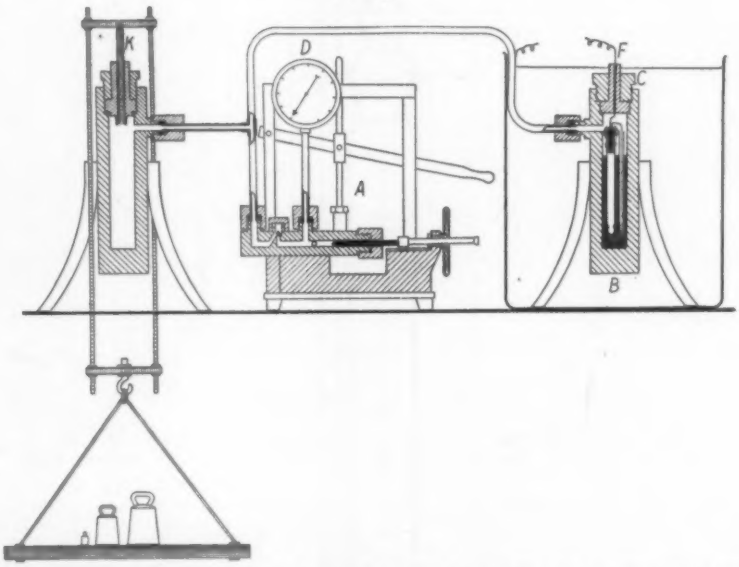


Comparison of heat evolved with contraction occurring during formation of equivalent quantities of chlorides. The upper zigzag line indicates the heat of formation; the lower zigzag line, the corresponding contractions in cubic centimetres.

the contraction was due to affinity; but he did not amplify the idea, which was buried in a footnote. Mueller-Erzbach, Hagen, Traube and others, who later rediscovered similar regularities, likewise failed to offer a complete and consistent explanation. The reason why the idea was received with so little favor, and has been indeed usually ignored, was doubtless due to the number of apparent exceptions. These exceptions were, however, not real exceptions; they only appeared to be in discord with the more regular phenomena, because the understanding of the case was not complete.

One essential aspect of the situation had, indeed, been entirely left out of consideration by all these investigators. Obviously the change of volume depends not only upon the *affinity*, but also upon the *compressibility* of the substances. Very compressible substances would show a greater change of volume with a given force of affinity than incompressible substances could show. That is the reason why chlorides were chosen for the diagram just

FIG. 3.



Apparatus for the determination of compressibility. The absolute pressure gauge is indicated on the left; the pump with lever for low pressures and plunger for high pressures stands in the middle, and the bomb containing piezometer is on the right. The piezometer is depicted on an enlarged scale in Fig. 4.

shown. Liquefied chlorine is a very compressible substance; it would therefore suffer great change of volume under pressure, and ought to be a good means of measuring chemical pressure. This substance, being common to all the cases concerned, should give an idea of the relative effect of the several affinity-pressures. In short, liquid chlorine may be imagined to act as a sort of chemical pressure-gauge.

Obviously in view of these considerations, it became essential to study the compressibilities of the various substances concerned in relation to their contractions on combination. Unfortunately, however, at the time that this comparison was first made (nearly

twenty-five years ago) only about half a dozen elements had been studied, even crudely, as regards their compressibilities. One reason for this lack of data was due to the great difficulty in making the determination. The values to be determined are very small, and in their determination every part of the apparatus

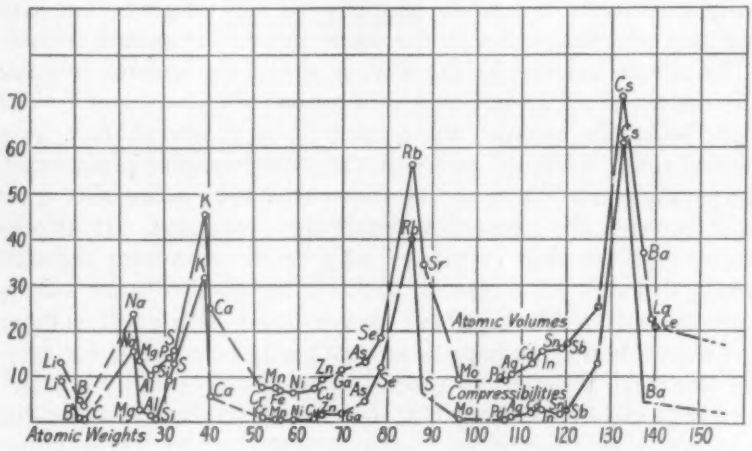
FIG. 4.

The piezometer.

changes in size with pressure, thus partially hiding the change of size of the substance to be investigated. It is not too much to say, therefore, that the determination of compressibility is one of the most difficult of all physico-chemical determinations. Not only were there no satisfactory individual data, but no satisfactory method existed for their determination. Accordingly a method was devised, employing apparatus sketched in the following diagrams. This consisted in an arrangement for producing pressure in a large bomb *B* (Fig. 3) within which was the piezometer or

apparatus for determining the change in volume of the substance. The whole piezometer was subjected to pressure, outside and in. It is depicted on a larger scale in Fig. 4, in its simplest form. The method consisted in first filling this glass tube with mercury—completely on the left-hand side and slightly above the fine platinum point on the right-hand side. It was then subjected to pressure until electrical contact was exactly established at the platinum point on the right-hand side, and the pressure noted.

FIG. 5.



Atomic volumes and compressibilities of solid elements, plotted in relation to atomic weights. The upper line gives the familiar atomic volume curve of Lothar Meyer; the lower line records the compressibilities of a number of solid elements determined at Harvard. Atomic volumes and compressibilities are both plotted as ordinates, the numbers indicating, respectively, cubic centimetres per gram-atom and compressibilities multiplied by 1,000,000. Atomic weights are plotted as abscissæ.

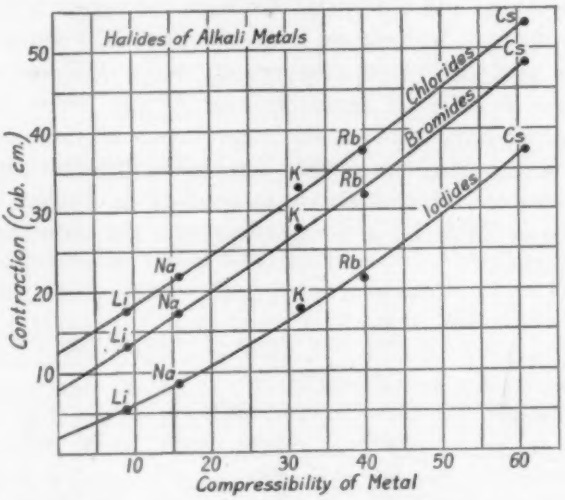
Subsequently a small weighed drop of mercury was introduced and the higher pressure necessary to reëstablish contact was recorded. Yet another drop of mercury needed yet a higher pressure. Thus a curve was drawn, showing the relation of pressure to added weights of mercury. After this relation had been established, a portion of the mercury in the left-hand arm of the piezometer was displaced by a quantity of some other substance to be investigated. The process of putting in successive drops of mercury and each time determining the pressure was repeated, giving another curve similar in type to the first. Obviously if the substance introduced had exactly the same compressibility as mercury, the two curves would be precisely similar.

Obviously, too, if they are different, the comparison of the two curves must give a means of computing algebraically the difference between the compressibility of the substance under investigation and that of mercury. The compressibility of mercury had been determined in another way with moderate accuracy by Amagat. With this method, the compressibilities of nearly forty of the solid elements were determined; the results are depicted graphically in relation to the atomic weights in Fig. 5. The results are highly interesting. They show not only that compressibility constitutes a periodic property of the elements, but also that this property varies in the same way as the atomic volume. (The atomic volume, by the way, is simply the volume in cubic centimetres of the atomic weight in grams, of any element.) The more bulky the element, the greater is its compressibility, as a general rule. Although evidently the proportionality is not exact, the parallelism of these curves shows that some connection must exist between the properties which they represent. It affords strong evidence that (whatever may be the case with chemical affinity) there is good reason to believe that great *cohesive* affinity (which holds solids together) is associated with small volume, and therefore may perhaps be at least partly responsible for causing this small volume. In general, when compressibility is small, we have a right to conclude that the internal pressure is large; that is to say, highly compressed substances are usually less compressible than slightly compressed substances. The heavy metals at the troughs of these curves are dense and comparatively incompressible. May not this density be due in part to the great cohesive pressure which holds them together; and which, because it is so great, has compressed them into a very compact, almost incompressible condition?

But we have made a wide digression from the main theme now under discussion, namely, the contraction which takes place on chemical combination. The object of the digression was to show the importance of compressibility in relation to this idea. We are now in a position to make a further advance in the argument. The next diagram shows graphically a comparison (made many years ago) of the *contractions* (which occur on combining the five alkali metals and chlorine) with the *compressibilities of the metals*. These figures are especially comparable for this purpose because the heats of combination of a given halogen

with the metals are not very different in the five cases, that is to say, the affinities are not very unlike. One is strongly impressed by the fact that the contraction increases as the compressibility increases. Evidently the contraction on forming the chloride is always greater than that on forming the bromide, and the contraction on forming the bromide always greater than that on forming the iodide. Part of the latter differences are doubtless

FIG. 6.



Graph depicting the compressibilities of the alkali metals compared with the contraction during the formation of their halides. Contraction on combination in cubic centimetres per mol is plotted ordinately; compressibilities ($\times 10^4$) of the elements are plotted as abscissæ.

to be ascribed to differences of affinity, and part are doubtless to be ascribed to different compressibilities.

The contraction plotted in this graph is, of course, the sum of two contractions, namely, the contraction suffered by the metal and that suffered by the non-metal, since both happen at once. Can we find out how much of the total contraction belongs to each? By extrapolating these lines to an imaginary metal of zero compressibility we obtain values for the contraction which may be due to the non-metal alone. These vertical distances on the extreme left of the diagram are the contractions which might be imagined to occur, for example, if chlorine or bromine were to combine with an absolutely incompressible metal. In the case of chlorine such a combination would thus cause a contraction of

12.5 c.c. If the guess is true, then, we have here a means of knowing how much of the contraction is due to the chlorine; and if we know this, we can easily find by simple subtraction how much is due each to lithium, sodium, potassium, etc., with which it combines. We have here not an exact solution of the problem, but nevertheless a means of attaining some idea as to the part borne by the two elements in a compound in making up the volume of that compound. For if we know how the contraction is shared by metal and non-metal, we have the actual bulk of each in the compound, because we know the original volume of each. Since we probably know very exactly from Millikan's investigations the number of atoms present in any given weight of substance, we have a means of computing from these considerations the actual diameters of the atoms in the different compounds. These diameters, which make no pretensions to absolute accuracy, are shown in Table II, in comparison with the estimates of two other theorists.

TABLE II.

Diameters (d or d') of Individual Atoms of Alkali Metals and Halogens (in Ångström Units).

	Landé.	Bragg.	T. W. R. In chlorides.	T. W. R. In bromides.	T. W. R. In iodides.
Chlorine	3.3	2.1	2.8	..	..
Bromine	3.6	2.4	..	3.1	..
Iodine	4.1	2.8	..	..	3.4
Lithium	..	3.0	2.3	2.4	2.6
Sodium	2.2	3.5	2.9	2.9	3.1
Potassium	2.9	4.2	3.5	3.5	3.7
Rubidium	..	4.5	3.8	3 8	3.9
Cæsium	3.2	4.7	3.8	3.7	3.8

Evidently a very thorough study of the behavior of solids under pressure is needful for the exact solution of the problem. This study has occupied much of my time for the last two years. It was based upon the actual compression which occurs when metals are subjected to very high external pressures, as well as upon their expansion when heated.

The way in which external pressure affects the volume of the metals under consideration is shown by Table III, which gives the loss of volume of potassium and sodium under pressure,

actually applied by a pump, as determined very recently by Prof. Percy W. Bridgman, of Harvard University.

TABLE III.

*Pressure-Volume Relation.**

Pressure (kg./cm.²).	$\Delta V/V_0$.	
	Potassium (at 45°).	Sodium (at 52.5°).
0	0.	0.
2,000	−0.0615	−0.0310
4,000	−0.1095	−0.0580
6,000	−0.1504	−0.0838
8,000	−0.1877	−0.1072
10,000	−0.2222	−0.1290
12,000	−0.2544	−0.1496

*According to P. W. Bridgman.

Thus potassium under 6000 atmospheres loses 15 per cent. of its volume; under twice the pressure (12,000 atmospheres) the additional loss is not much over 10 per cent., the total diminution in volume being somewhat over 25 per cent., or one-quarter of the original bulk. Great as this pressure of 12,000 atmospheres is, it is not nearly as great as the internal pressures which must exist in most solid substances. In order therefore to interpret these relations—in order to judge very high pressures from the volume changes suffered by substances when they chemically combine—it is necessary to know accurately the laws which underlie these pressure-volume curves. Accordingly I have spent much time recently in endeavoring to discover these laws from the experimental values obtained by Bridgman as well as from those which have been ascertained at the Wolcott Gibbs Memorial Laboratory. The first hopeful outcome was the discovery that a very simple hyperbolic equation [1] represents with great precision the effect of pressure and temperature on the volume of heavy metals, like gold and silver. This equation takes the form

$$(p + P)\ (v - B_1) = k_1 + cT. \qquad (1)$$

[1] Subsequently I found that somewhat similar equations had been used over short ranges for organic substances by Tumlirz, *Sts. Akad. Wiss. Wien*, 118, IIa, 203 (1909), and Tammann, *Ann. Phys.*, 37, 975–1013 (1912). Their treatments do not apply to the present case, however.

In this equation p represents external pressure applied by a pump and measured by a gauge; P represents the hidden internal cohesive pressure which holds the metal together, v is the volume, B_1, k_1, and c are constants, and T is the temperature recorded in the absolute scale. The excellence of the agreement of the predictions of the equation with the facts as determined by Bridgman is shown in the accompanying table.

TABLE IV.

Comparison of Hyperbolic Equation with Observed Values (in Terms of Megabars).

Silver ($\alpha = 0.0000556$).

Equation $(p + 200{,}780)\ (v - 0.7978) = 37.327 + 11.16\ T$.

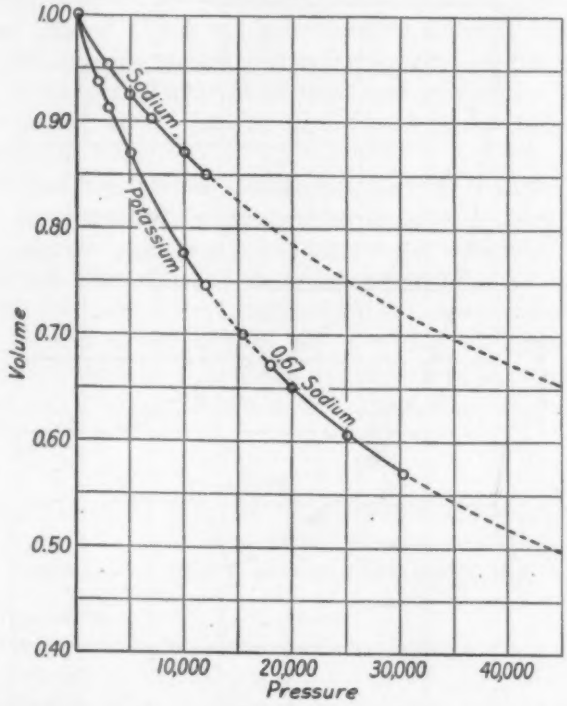
	Volumes at 20°.			Volumes at 75°.		
p	Obs.	Calc.	Error $10^4\ \Delta$.	Obs.	Calc.	Error $10^4\ \Delta$.
0	1.00000	(1.00000)	0	1.00306	(1.00306)	0
2,000	0.99801	0.99801	0	1.00103	1.00099	−0.4
4,000	0.99606	0.99605	−0.1	0.99904	0.99905	+0.1
6,000	0.99415	0.99413	−0.2	0.99708	0.99710	+0.2
8,000	0.99227	0.99225	−0.2	0.99516	0.99519	+0.3
10,000	0.99043	0.99045	+0.2	0.99326	0.99332	+0.6
12,000	0.98862	0.98860	−0.2	0.99144	0.99144	0

Many other similar results might be shown. The agreement is certainly within the limit of error of the experiments.

The curve represented by the equation just given deviates appreciably from the observed results when the change of volume is great, that is to say, with the very compressible metals. It is hardly safe therefore to extrapolate these equations for any considerable distance (that is, to prolong the curved line beyond the range of actual experiment), if perfectly precise results are wished. In default of knowledge of the exact continuation of the curve a device presented itself as follows, namely, the possibility of drawing conclusions as to the way in which compressible elements would behave under great pressure from the way in which more compact elements (which must have within them already great internal pressures) behave under moderate pressures. The moderate pressure would thus be added to the great internal pressure. This somewhat complicated idea may be made clear by the next diagram (Fig. 7), which gives Bridgman's results for change of volume of sodium and potassium under pressure. It

is simply a connected graph of the results recently shown in tabular form. Now sodium is a metal very much like potassium, except that it acts in many ways as if it had a much greater cohesive pressure. In other words, it acts very much as potassium prob-

FIG. 7.

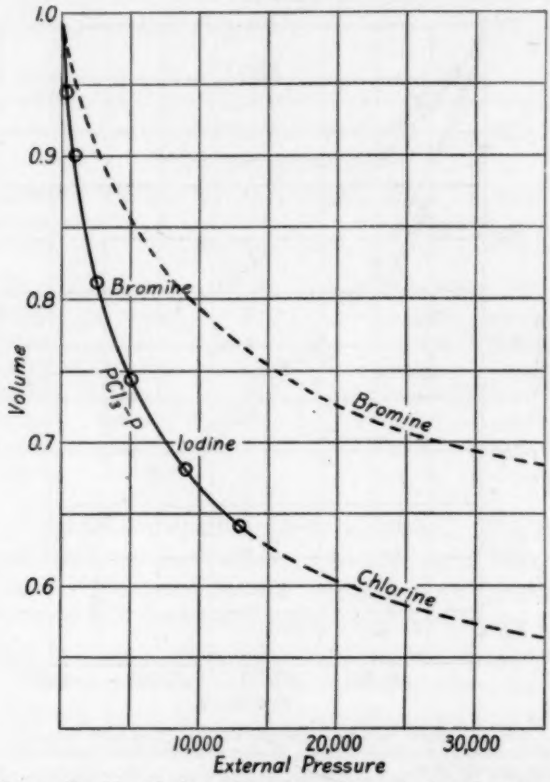


Changes of volume suffered by potassium and sodium under great external pressures (the latter in kilograms per square centimetre). Continuous lines are experimentally determined; broken lines are hypothetical.

ably would if subjected to a pressure of fifteen or twenty thousand atmospheres. In the absence of direct experiment then, one may suggestively use the sodium values for an extrapolation of the potassium values. As a matter of fact, they form a very plausible continuation of the potassium curve, as Fig. 7 shows. This gives us, then, at least a guess as to how the potassium might behave under pressures so great as to be quite unattainable experimentally. In the same way we can guess at the performance of chlorine under pressure by comparing its behavior with bromine

and iodine and with the chlorine in a combined state such as the trichloride of phosphorus; the next diagram (Fig. 8) shows about the sort of curve which one would expect from the performance of that very compressible substance, liquid chlorine,

FIG. 8.



Changes of volume suffered by chlorine and bromine under great external pressures. Continuous lines are experimentally determined; broken lines are hypothetical.

under great pressure. Both this diagram and the one for potassium are drawn for unit volumes. In order to find the total contraction which happens when potassium chloride is formed, one must, of course, take account of the proportions of potassium and chlorine in potassium chloride. In other words, one must translate these changes of volume into terms of the atomic volumes of the substances concerned. Evidently (in a way which is shown in detail in a paper published in February, 1923, in the

Journal of the American Chemical Society), by making an assumption as to the difference between the initial pressure of potassium and chlorine, one can find from these curves how much of the contraction in forming potassium chloride comes from the chlorine and how much from the potassium. Millikan's results, here again, give us the means of applying these effects to the individual atoms. Thus we have another solution of the same problem which was solved less satisfactorily by the curves in Fig. 6. This second method of treatment gives, as a matter of fact, almost the same values as those found by the other method, as is shown in Table V.

Of course, the curves just shown for the contraction under pressure of potassium, sodium, chlorine and bromine are only approximate; no claim was made for perfect accuracy. It seems now probable that none of these curves turns quite as sharply toward the horizontal as is indicted by the extrapolations in the graphs. Since, however, they are probably all affected more or less in the same way, this revision of their several courses makes no important difference in the conclusions concerning the diameters of the atoms.

TABLE V.

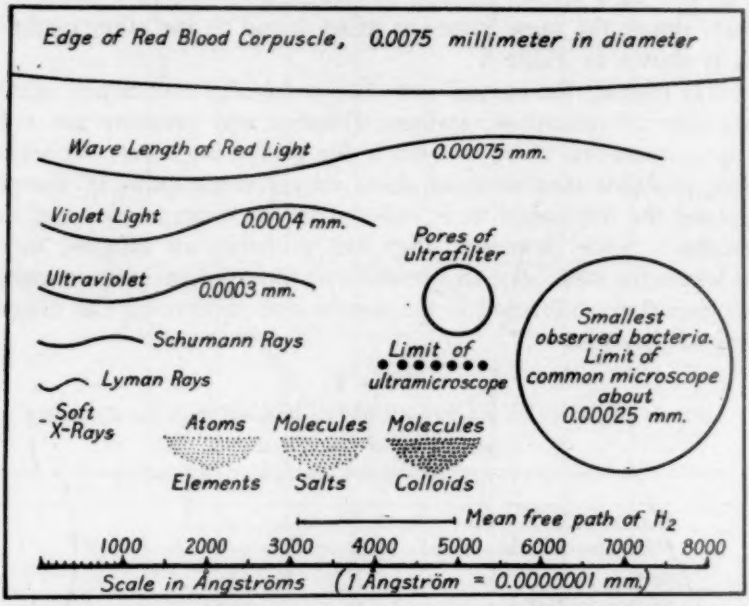
Atomic Diameters (in Ångström Units) Computed from the Estimated Compression of the Elements.

	New.	Old.
Potassium in KCl	3.46	3.5
Potassium in KBr	3.56	
Sodium in NaCl	2.85	2.9
Sodium in NaBr	2.92	
Chlorine in KCl	2.82	2.8
Chlorine in NaCl	2.78	
Bromine in KBr	3.04	3.1
Bromine in NaBr	3.03	

A diagram (Fig. 9), drawn to scale, gives the best means of appreciating the extreme smallness of these diameters thus measured. This diagram, which is perhaps worth giving, although it contains nothing new, gives the diameters of the atoms in relation to certain more or less familiar dimensions of other kinds. The length of a printed line on the page, on the scale of Fig. 9, is equivalent to less than the thousandth of a millimetre. A

pin's head a millimetre in diameter would be shown, when enlarged to the scale of this diagram (as printed), to be over a thousand times as great as the width of the page, or nearly 400 feet, a green pea would be nearly three-quarters of a mile in diameter, and a good-sized orange would be about seven miles in diameter. On this scale atoms would be nevertheless so small that they cannot be given exactly by the smallest printable dots. In order to

FIG. 9.



Very small magnitudes drawn on a greatly enlarged scale. On this scale a pin's head would be 400 feet in diameter, a green pea would be 4000 feet in diameter and an orange would be about seven miles.

make the matter more vivid, a further diagram (Fig. 10) is given, which depicts the smallest objects exhibited in the previous one, enlarged about a hundred times more. Fig. 1 is drawn on a scale yet 3.5 fold greater.

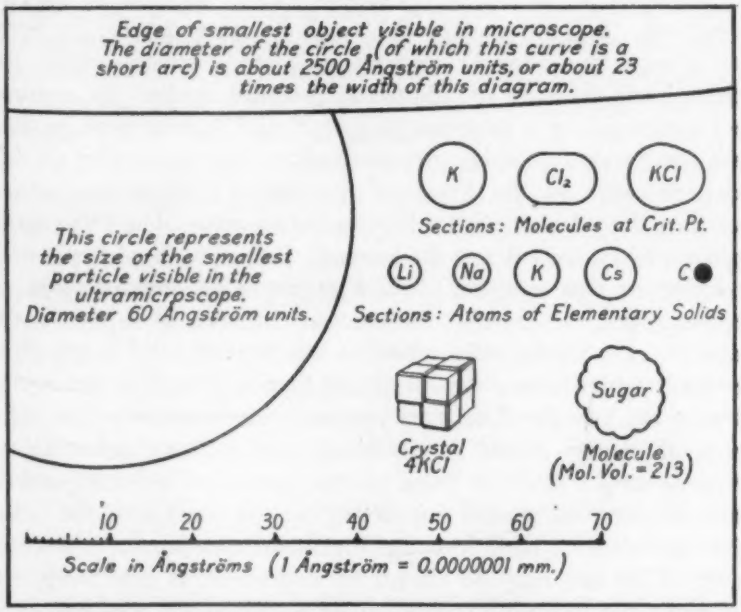
More recent investigations have made it possible to advance a step further toward the understanding of the internal pressure of metals. The first procedure that brought a better understanding of these pressures was the transformation of the hyperbolic energy-equation (1) on page 13 to a pressure equation. This very simple transformation of the hyperbolic equation was

effected by dividing it through by the volume $(v - B_1)$. Thus we have

$$p + P = \frac{k}{v - B_1} + \frac{cT}{v - B_1} \qquad (2)$$

The transformed equation still has four terms, but now each represents a pressure. The first term p is simply the external pressure;

FIG. 10.


Edge of smallest object visible in microscope. The diameter of the circle (of which this curve is a short arc) is about 2500 Ångström units, or about 23 times the width of this diagram.
This circle represents the size of the smallest particle visible in the ultramicroscope. Diameter 60 Ångström units.
K
Cl2
KCl
Sections: Molecules at Crit. Pt.
Li
Na
K
Cs
C
Sections: Atoms of Elementary Solids
Crystal 4KCl
Sugar
Molecule (Mol. Vol. = 213)
10
20
30
40
50
60
70
Scale in Ångströms (1 Ångström = 0.0000001 mm.)

Very small magnitudes drawn on a scale 100 times greater than in Fig. 9. On this scale a green pea would be nearly seventy miles and an orange nearly seven hundred miles in diameter.

the second represents pressure caused by *cohesion*, the third represents that portion of the *distending* tendency which is independent of heat, and the last the distending pressure caused by heat.

This outcome reminds one at once of another equation, which is not usually found in textbooks, but which is nevertheless convenient for the purposes of making clear to beginners the equilibrium of pressures determining the existence of all substances, solid, liquid, or gas. This other equation runs as follows:

$$p + \Pi = \Pi_\rho + P_\theta \qquad (3)$$

Perhaps the reason why this equation is usually ignored is because

the two middle terms Π and Π_ρ are beyond the range of classical thermodynamics. On the other hand, the first and last term have easily comprehensible thermodynamic significance, the first being simply the external pressure, and the last the pressure produced by heat in a substance, which causes it to expand.

Evidently, as I have said, its terms have essentially the same physical significance as the corresponding terms of equation (2), although the two middle terms are not exactly identical in the two equations. Let me explain the terms in more detail. In both, p is always the external pressure, as already stated—either the atmospheric pressure or additional pressure applied by a pump and measured on a pressure-gauge—P and Π represent in each case the internal cohesive pressure (or at least a function of this pressure) due to the force of the cohesive attraction, which prevents the substance from turning into a gas. The third term, typified by Π_ρ, represents the internal distending tendency (or a function of this tendency) which exists in all substances at all temperatures, even at the absolute zero; it must be a part of the nature of the atoms independent of temperature, and is the chief tendency which causes the solids and liquids to occupy space. If it were not for the distending pressure represented by this third term, all matter would shrink into a mathematical point at the absolute zero. Both of these internal pressures are supposed to exist *between the atoms,* not merely on the surface of the solid. The last term of each equation represents the pressure-effect of heat. This last may be shown by a process of reasoning, too extended for exposition here, to be equal to the absolute temperature multiplied by the coefficient of expansion and divided by compressibility ($T\alpha/\beta$). Thermodynamically it is a valid quantity, equal to $-T\left(\frac{\partial p}{\partial t}\right)_v$.

The chief difficulty with equation (3) is that since Π and Π_ρ are internal pressures, they give little outward sign if both increase or decrease simultaneously. There is no rigorous thermodynamic method of computing their value in a given case. There are, however, many reasons for believing that they both increase rapidly as the volume diminishes. We may therefore amplify equation (3) in the manner shown in equation (4), which makes both of these pressures dependent upon volume. This latter

assumption is not a wholly new idea: Grüneisen adopted it twelve years ago,[2] having amplified an earlier proposition of G. Mie.

$$p + \Pi_o \left(\frac{v_o}{v_1}\right)^m = \Pi_{\rho_o} \left(\frac{v_o}{v_1}\right)^n + \frac{\alpha T}{\beta} \qquad (4)$$

This equation appears to be rather complex, but the ideas concerned are really simple enough. The equation simply puts into symbolic language the concepts just stated. The two exponents m and n are not necessarily constant with varying volume, but at any given volume they may represent closely the rate of increase of Π and Π_ρ, respectively; n is ordinarily greater than m.

This equation (4) is a distinct step forward. By assuming suitable values of its several quantities, one can construct curves which are exactly similar to the pressure-volume curves of metals; and by constructing hyperbolic equations from these, one can determine accurately the relation between the hyperbolas (equation (1)) and the more complicated but more rational curves, corresponding to equation (4). These enable us to relate such equations as that given for silver (Table IV) to the rational equation (4). Nevertheless, although a decided step forward, these equations still do not give a complete solution of the problem, since the number of variables is so great, and the possible experimental errors so considerable, that the outcome is only approximate.

There is, however, fortunately another method of attacking the matter, which, granting a fairly reasonable assumption, gives a much more definite outcome. This method depends upon the coefficient of expansion—a property allied to compressibility, and like the latter concerned with the great internal pressures existing in solids and liquids. The coefficient of expansion of a solid is always much less than that of a perfect gas. The probable reason for this difference may well be as follows. In solids the pressure produced by heat must be only a small part of the total pressures concerned (as is shown by equations (2), (3) and (4)), whereas in the case of a perfect gas the energy of heat must cause the whole distending effect. Is it not then reasonable to draw an inference concerning the magnitude of this greater pressure from the comparison of the two coefficients of expansion? The coeffi-

[2] E. Grüneisen, *Ann. Phys.*, **39**, 257 (1912). References to the work of others in this direction will be found in the last article of the appended bibliography.

cient of expansion of silver at 20° is less than one-sixtieth of that of a perfect gas. The kinetic energy involved is generally believed to be identical in the two cases. May it not then be that the total pressure involved in the expansion of silver is 61.2 times that which a gram-atom of a perfect gas would exert in the same volume? If this is the case the internal pressure of a metal at 20°, for example, would be

$$\Pi = \frac{RT}{V_A}\frac{0.00341}{\alpha} = \frac{R}{V_A\alpha} \qquad (5)$$

an expression which makes precisely this comparison. In this expression Π, as before, signifies cohesive internal pressure, while T signifies the absolute temperature; R, the gas-constant; α, the coefficient of expansion, and V the atomic volume.

There is nothing newly iconoclastic in the application of the gas law to the whole volume of a solid, since the ancient picture of a "hard" atom or bulky hard atomic core has been already effectually shattered in the last twenty-five years by attacks from different directions.

In this way the internal pressures existing in metals have been computed as shown in Table VI, pressures which seem to me at present to be the most reasonable values which have thus far been given. The pressures are recorded in terms of megabars, or "absolute atmospheres"—a unit 1.3 per cent. less than the ordinary "atmosphere."

These pressures are at least reasonable in their respective orders of magnitude. They are, relatively to one another, about as large as we should expect them to be, judging from those properties of the elements which represent closely knit structure. For example, everybody would naturally expect that the internal pressure in tungsten would be the largest of all the metals, because this metal is the least volatile and the least compressible of all.

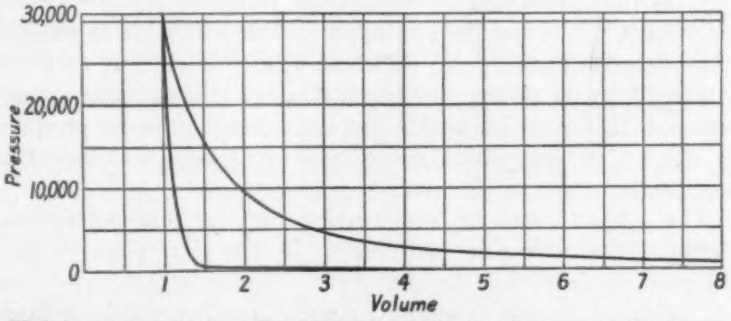
The heat of evaporation of mercury affords support for the corresponding value given in the above table, and therefore indirectly for the other values. When the attracting and repelling pressures are known, one should be able to compute the work required for pulling the atoms apart, in other words, for evaporating the substance. This work (when due correction for such small concomitant effects as external work and heat expelled because of change of heat capacity is made) should be equal to the heat of evaporation. The idea is easily represented graphically.

TABLE VI.

The Internal Pressure of Isotropic Metals under Atmospheric Pressure, Based on Molecular Volume and Cubic Coefficient of Expansion (at 20° C.).

Metal.	Coef. Expans.	Mol. Vol.	Internal Pressure.
Cæsium	300	71	4,000
Potassium	245	45.4	7,500
Sodium	215	23.7	16,300
Mercury	181	14.8	31,000
Lead	85	18.3	53,000
Calcium	50	25.3	66,000
Magnesium	74	13.3	85,000
Aluminum	65.5	10.1	126,000
Silver	55.6	10.3	145,000
Gold	43.2	10.2	189,000
Copper	48.4	7.1	242,000
Palladium	34	8.77	279,000
Tantalum	24	10.9	315,000
Nickel	38	6.7	327,000
Cobalt	37	6.85	329,000
Iron	34	7.1	345,000
Platinum	26.4	9.1	347,000
Tungsten	13.7	9.6	632,000

FIG. 11.



Work due to pressure-volume effect involved in evaporation of mercury (20°C.). Pressures in megabars are plotted in the direction of ordinates; volumes in terms of multiples of the atomic volume are plotted as abscissæ. Hence each square represents 37 litre-megabars. The total area between the curves may be interpreted to represent the major effect involved in the heat of evaporation.

In Fig. 11 the cusp at 31,000 megabars represents the equilibrium of the pressures at the ordinary atomic volume. The curves toward the right represent, respectively, the change of the cohesive pressure Π and the change of the repelling pressure Π_ρ as the volume increases, calculated from the compressibility according to the principles just enunciated (the respective exponents being $m = 1.7$ and $n = 9.8$). The area between these curves should

represent the work involved in evaporation. Since the series of areas are convergent, it is easy to find what the area would be if the curves extended to infinite volume. In other words, the total area between the curves may be found by integration. The total in this case amounts to about 55 kj., whereas the heat of evaporation duly corrected for external work is about 56 kj. The agreement is so close that it must be partly accidental; there can be no doubt at least that the order of magnitude of the two quantities compared is the same.

These considerations are not so easily applied to compounds as they are to elements which crystallize in the regular system, because in compounds different parts of the atom must have different compressibilities and different coefficients of expansion. Naturally only an average value would be obtained by the methods described this afternoon; these methods are not able to discriminate between the different sides of an atom. Moreover, of course, if any molecular change takes place, such as that which probably happens in water when it is heated or compressed, the methods described to-day can be of little use. All these refinements of interpretation, however, go beyond the range of possible discussion to-day. It is my hope to apply in the future these methods to the pressures caused by chemical affinity, and thus to throw more light on the nature of this elusive but all-important agency. Even now it is possible to state that the average pressure produced by affinity in potassium chloride is probably not less than 40,000 atmospheres.

The subject of to-day's discussion may be summed up very briefly in the following sentences. In the first place, I have attempted to show that the changes of volume which occur when two solids or liquids combine to make another solid or liquid are probably to be referred (at least in large part) to the changes of pressure resulting from chemical affinity and cohesion. The argument rests upon the fact that where the affinity is greater the volume-change is greater, and likewise where the compressibility is greater the volume-change is greater, other things being equal in each case. From these ideas, two methods for determining the diameters of atoms in compounds were developed. The rest of the discussion has dealt with attempts to discover the laws which regulate these changes of volume under various pressures, in order that unknown internal pressures may be computed and that the

effect of affinity on the volume may be reduced to a quantitative or numerical basis. In the course of this argument I have endeavored to show how, proceeding from one mathematical equation to another, one can gradually evolve a fairly definite picture of the pressure to which solids are subject by cohesion; and also of the way these pressures change with changing volume. Finally a number of values were given for the internal pressures existing in common metals, computed from their coefficients of expansion. These pressures are sometimes enormous—very far beyond the range of experiment. They are not directly manifest externally, because they balance one another within the substance according to the simple equation

$$p + \Pi = \Pi_p + T\frac{\alpha}{\beta}$$

an equation of condition, which states as succinctly as possible the balance of pressures existing in a substance under all conditions. The inevitable assumptions involved seem to be reasonable, and as simple as possible. This equation is really the keynote of the discussion. The outcome of the whole argument gives a rather new picture of the forces which determine structure of the solids and liquids—a structure upon which our life depends.

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Linking New York and New Jersey.—One of the most ambitious engineering projects attempted in recent years is the building of the Hudson River vehicular tunnel, which will link New York to New Jersey in the most efficient way yet devised. Traffic between the two states is at all times very heavy, and because of New Jersey's popular resorts, week-ends and holidays bring a congestion of automobiles that is far beyond the capacity of the existing ferry services.

There will actually be two tunnels, one for east-bound and one for west-bound traffic. Each will be twenty-nine feet six inches in diameter, and 9250 feet long. The roadways will be twenty feet wide and have an overhead clearance of thirteen feet six inches. The rest of the space will be required for the ventilating system, which consists of air ducts at the top and bottom of each tunnel. Fresh air under compression will be forced into the lower duct and from there into the roadway itself through air flues and expansion chambers placed at intervals of fifteen feet along each side of the tunnel. This will force the vitiated air out through openings, also at fifteen-foot intervals, into the top duct, whence it will be drawn out by large fans and discharged through the caissons at the ends of the tunnels.

The tunnels are being constructed from both ends and will meet somewhere in the middle of the river. The calculations on the work are so accurate that when the tunnels meet they will not deviate half an inch. The tunnels are built in ring sections of fourteen cast-iron plates, each plate weighing a ton and a half. The excavating is done

in shields, or movable heads, which are pushed forward two and a half feet at a time by thirty hydraulic jacks. As the shield moves forward, the rings are added one by one. When completed the tunnels will have a protective covering of broken stone, and at each entrance there will be a modern pier above the tunnel as it reaches the land, in order to avoid the possibility of a ship running into the tunnel where it comes up.

One of the most difficult problems in connection with building the tunnel has been proper illumination. The Illuminating Engineering Laboratory of the Westinghouse Lamp Company recently became interested in this problem and began a series of experiments to determine the best possible lighting system. In order to study all suitable systems of illumination under approximate operating conditions, an exact model of the tunnel on a scale of one inch to one foot, and ten feet long, was constructed. Exact replicas of the proposed lighting units were installed in this model tunnel, furnishing an amount of light corresponding accurately to the desired illumination. The model tunnel is complete to the most minute detail, even the brass railing along the walk for pedestrians being provided.

It would seem at first glance that lighting the tunnels would be merely a matter of installing plenty of units, but that is not the case. It is necessary in the first place to eliminate all glare, so the units, one every twenty feet, were encased in metal boxes sunk into the concrete of the tunnel, and diffusing glass used to cover them. Next, the lights had to be so placed as to secure the greatest possible amount of reflected illumination from the walls and ceiling. Third, and most important, it is extremely necessary that all shadows between cars be eliminated insofar as possible, as sharp shadows would cause drivers to misjudge distances, which might result in accidents. As the new tunnel is expected to relieve the traffic congestion on the west side of New York, any accidents or tie-ups in the tunnel must be rigorously guarded against and proper illumination will be an important factor in accomplishing this. H. L.

The Change of Wave-length Produced by Diffusion in the Case of K-rays from Tungsten. M. DE BROGLIE. (*Comptes Rendus,* March 10, 1924.)—Working with X-rays from a molybdenum target Compton found that after they had been diffused from graphite they had a slightly different wave-length from that possessed when they left the target. To test the correctness of this result the French savant let K-rays of tungsten emitted in a Coolidge tube fall upon a secondary radiator with a flat surface, one part of which was covered by powdered metallic tungsten and the other by carbon. The same plate of the spectrograph records the rays that come from the carbon by diffusion and those emitted by the tungsten through fluorescence. The image showed two distinctly separated rays. Quantitatively the results correspond well with the theory of Compton and Debye. G. F. S.

THE APPLICATION OF RADIO ENGINEERING PRINCIPLES TO SUBMARINE TELEGRAPH CABLES.*

BY

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Major General, United States Army; Franklin Medallist, Honorary Member of the Institute, Associate Editor.

IT IS perhaps a far cry from electromagnetic waves of frequencies of a million or more per second, used in space radio, to frequencies of the order of five to ten per second which represent those at present employed in ocean cable practice. In 1910, the writer applied the engineering methods and apparatus of the then-existing radio art to the case of metallic wires on land, by employing the hitherto unused band of frequencies extending from about 15,000 to about 100,000 per second, which at that time represented the lowest limit of frequencies used in the radio art.

It is perhaps not overstating the case to say that the fundamental step taken in those experiments in 1910 has resulted already in revolutionizing the engineering practice of multiplex telephony and telegraphy on wire circuits and wire networks. The new art of "line radio" has taken its place definitely as a distinct branch of radio, in the principal countries of the world, and is rapidly extending its scope to include telephony and telegraphy and music superimposed upon long-distance high-voltage power lines, and to broadcasting service over standard commercial wire networks used in distributing light, heat and power to the public.

The object of this paper is to propose a *second* fundamental step, analogous to the one taken in 1910, by the application of line radio engineering methods and apparatus to the case of ocean cable circuits.

Although comparisons are odious, it can be scarcely denied that the very recent achievement of long-distance broadcasting of music and speech represents a new high level of attainment of the electrical engineering profession as a whole. It behooves us to analyze carefully its vital processes and transformations and apply these intelligently to new fields, such as that of ocean cables and the electrical transmission of power.

* Communicated by the Author.

The engineer who grasps the fundamental ideas involved in generation, modulation, transmission, amplification, and detection or rectification, as illustrated by the broadcasting of speech and music, starts from what may be considered to be, theoretically, the basis of all systems of communication by electromagnetic waves, whether through the ether of space or guided by the wires of land lines or submarine cables.

On this view, even the older methods of direct current telegraphy fall in line as special cases of the general case of broadcasting, where the frequency of the carrier wave is reduced to zero and the wave is guided by a wire, the modulator becoming the hand-key or automatic.

Although, as will be described presently, marked developmental progress has been made already, based on this viewpoint, yet it is a specific engineering "attitude of mind" toward the whole problem of ocean cable communication that I wish to emphasize in the present brief paper on this important subject.

GENERAL CLASSIFICATION OF CIRCUITS FOR ELECTRICAL COMMUNICATION.

To fix the ideas we may classify all electrical circuits as:

(I) Distortionless circuits—radio or *line radio*.

(II) Circuits with distortion—long land lines, subterranean, and submarine cables.

In Class I circuits, of course, all frequencies are transmitted with equal efficiency and in space radio at the velocity of light, with the result that, as far as the medium itself is concerned, the very complex wave representing an orchestra concert or a chorus of voices, arrives at the receiving antenna attenuated enormously, but of practically the same shape as the wave radiated from the transmitting antenna.

In the case of long submarine telegraph cables, as now constructed, with resistance, large distributed capacity and negligible leakance and inductance, we have the extreme case of distortion of Class II circuits.

Long land lines, and any combination of these with subterranean cables, fall between these two limiting cases, so that if we fully comprehend the extreme limiting cases, we possess the key to the solution of any case.

In long submarine cable circuits, as now operated, the distortion at high speed, with the exception of a certain group of five

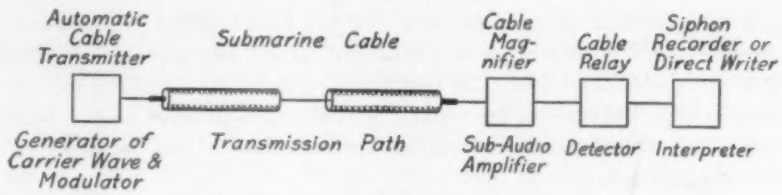
letters of the alphabet, is so great that there is little resemblance between the shape of the wave entering the cable and its shape at the receiving end of the cable. The velocity of transmission of the wave through the cable is reduced from the velocity of light to a very few thousand nautical miles a second, and the attenuation is relatively much greater as the frequency is increased.

In Class I circuits, therefore, other things being equal, we are at liberty to use frequencies of an extremely wide range at the transmitter, while in Class II circuits the slightest change of frequency produces a distortion which reaches its limit in ocean cables.

THE KEY PLAN.

In Fig. 1 are shown schematically the essential elements and transformations necessary and sufficient for operating a single

FIG. 1.



Key plan.

span of ocean cable at present, and also the corresponding steps of the process from a radio-engineering viewpoint. In cable practice, we start with the present automatic cable transmitter which includes a battery source of power, by which the signals are impressed upon the cable. They are transmitted to the distant end of the cable, where the signals are first received by a cable magnifier and then pass to the cable relay, and finally to the cable recorder, or direct writer, for interpretation.

To simplify as much as possible, only simplex working and a single span of cable need be considered, whereas all important cables are actually operated duplex, and usually several spans of cable must be worked together in a single chain for through traffic.

In the design of the chain of apparatus, indicated in Fig. 1 by the upper line of present cable apparatus, we find only what has survived the " acid test " of long years of actual practice. The present automatic cable transmitter is a marvel of mechanical skill by which the punched paper tape causes a battery to impress upon

the apex of the duplex bridge square-topped waves according to the present cable Morse alphabet, or a modified international Morse alphabet. In the best practice, the speed of this transmitter is accurately controlled by a tuning fork. At the receiving end of the cable, the magnifier and all forms of cable relays still employ the moving coil d'Arsonval galvanometer principle, originally introduced into cable signalling by Lord Kelvin.

The engineering note throughout this chain of apparatus is one of the older Art, and it can be said truly that, with the exception of the new Bruce relay employing vacuum tube potential contacts, no new basic principle has been introduced into cable practice for many years. In particular, nearly all advancements made have been directed to improving the receiving conditions only, the type of signals transmitted remaining the same as in the beginning.

In the lower line of names of Fig. 1, we have suggested the principles which have made radio and line radio such a phenomenal success. Each step from left to right in the key plan represents one which is to be found in every up-to-date broadcasting operation which we set out to regard as the most general case, from which all other cases of electrical communication can be deduced as special cases.

Although in the limiting case of Class II circuits represented by an ocean cable, the one thing to avoid in forming the signals is to introduce changes of fundamental frequency, for the reasons discussed above, yet the present cable Morse alphabet may be described as one actually based on changes in fundamental frequency to distinguish the different letters of the alphabet. This will be apparent from the following.

THE PRESENT CABLE MORSE IS A VARIABLE FREQUENCY ALPHABET CHANGING 100 PER CENT.

When two successive pulses of the same polarity are sent into a cable, the current does not return to zero value at the transmitting end and as a consequence there is a piling up effect which tends to displace the recording siphon, for instance, at the receiving end off toward the edge of the tape, and makes it harder to read because there is little distinction in the record between the successive pulses, they being both merged into one large one. The reason for this is clearly brought out when the following fact is considered. If a continuous stream of pulses of the same

polarity is sent into the cable in succession, the record shows a wavy line which starts from the centre of the receiving tape and oscillates about a medial line which is displaced quickly or at a sharp angle to one side, but gradually comes back to the centre of the tape. After the record has returned to the centre of the tape (the return being due to the presence of a condenser or condensers in the line circuit) its appearance cannot be readily distinguished from the record produced by a simple sine wave alternating current. In fact, the same record can be made in two ways, first as above, and second by using an alternating current of double the frequency.

The conclusion is that the use of pulses of the same polarity successively is equivalent in record to an alternating current of double the frequency, and that as the first signals to become illegible are those having two successive pulses of the same polarity, the use of characters produced by a succession of pulses of the same polarity is detrimental to speed, and that an alphabet having no successive waves of the same polarity is superior to one having them, in legibility at the receiver. A greater speed of transmission is therefore allowable before the limit is reached.

To illustrate, in the present cable Morse alphabet, the five letters, A, C, K, N and R, are transmitted with one fundamental frequency of alternating current, while the five letters, H, I, M, O and S, are transmitted with just double this frequency, corresponding to the first harmonic of the first group; the other letters are transmitted with an equivalent frequency between these limits. The letters E and T indeed are, technically, in a class by themselves, each being formed by a single semi-sinus of current.

It thus appears that in all the years of the operation of ocean cables, the speed of transmission of the entire traffic has been held down by the five letters, H, I, M, O and S, due to the inherent frequency defects in the impulses of those letters.

Obviously, the ideal alphabet to employ in cable signalling is one in which, other things being equal, each letter has the same limit of legibility at the receiver.

In 1913–15 the writer gave consideration to this subject and designed such a form of cable alphabet.[1]

[1] *Proc. Phys. Soc. London*, Vol. xxvii, Part V, August 15, 1915; JOUR. FRANK. INST., 195, 5, 633, May, 1923.

Referring again to Fig. 1, this form of alphabet would be defined in two ways, as follows:

In present cable language:

An alphabet in which the signals are formed by an unbroken alternating current of a single frequency, the amplitude of whose waves is varied individually to represent dots, dashes and spaces.

In radio language:

An alphabet in which the signals are formed by an imaginary carrier wave of one definite frequency completely modulated by a modulating wave of the same frequency and in phase with the carrier wave.

In the broadcasting model, we find a carrier wave of one constant frequency and constant amplitude, modulated by a large number of different frequency waves, representing the different tones of an orchestra or voice chorus, even to the harmonics producing the quality or timbre.

In the alphabet as defined above, this highly complicated process is reduced to its lowest terms beyond which we cannot go. The modulating frequencies have been reduced to one, and this one frequency has been reduced also to the same value as the carrier wave itself and in phase with it. On this view, the letters of the alphabet become scientifically simplified speech, which perhaps is a proper definition of what telegraphy was originally intended to be.

Present cable operation may be compared to a patient who has been doctored for many years and now requires a major operation to start him on the road to complete recovery. This operation consists in redesigning the alphabet itself according to the latest engineering practice in the radio art.

Once this fundamental step is taken, it will be shown that improvements and simplifications follow logically in several directions.

EXPERIMENTAL RESULTS.

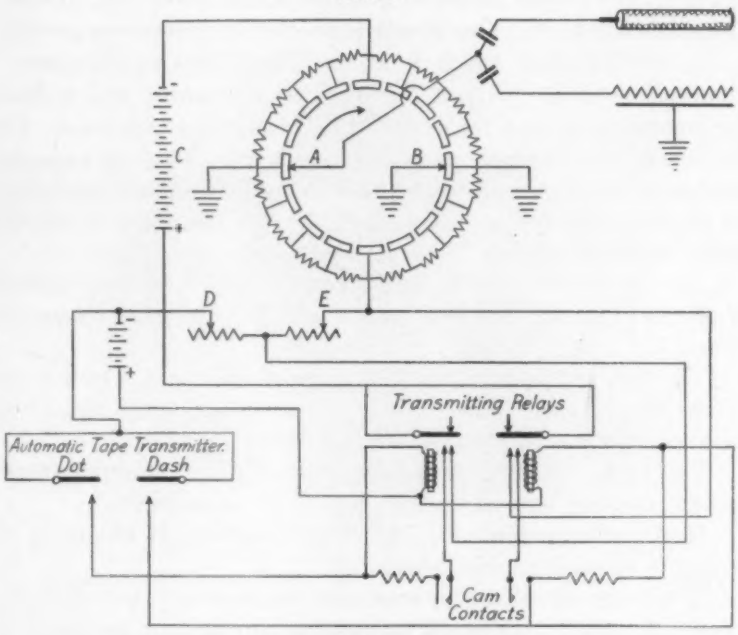
In the Army Appropriation Act for the fiscal year 1923–24, funds were authorized by Congress for the replacement of the Signal Corps Alaskan cable system from Seattle, Washington, to Ketchikan, Alaska, and to certain points beyond. Under this appropriation, a developmental contract was entered into in May, 1923, between the Signal Corps of the Army and William M.

Bruce, Jr., the well-known cable engineer. Experiments have been carried on during the past year at the laboratory of Mr. Bruce, at Springfield, Ohio, in accordance with the ideas of the key plan. (Fig. 1.)

A UNIVERSAL TELEGRAPH TRANSMITTER.

The first step required was the design of a transmitter mechanism which would automatically transmit the radio type of alphabet

FIG. 2.



Alternating current cable transmitter.

described above. The writer had previously constructed a special type of cable dynamo for this purpose which is described in a paper presented to the Physical Society of London in 1915, referred to previously. Careful tests were first made with this dynamo, transmitting through a suitable artificial cable in the laboratory. It was finally decided to supersede the dynamo type of transmitter for various reasons, and design a transmitter which would employ the usual storage battery at present used on cables as a source of power.

In Fig. 2 is shown a wiring diagram of this transmitter as

constructed and tested. The only change required in present automatic cable transmitters, which have stood the test of actual practice for years, is to provide a mechanism by which the regular battery, now employed to send square-topped waves according to the present cable Morse alphabet, shall send waves of the sine wave type always alternating in sign and changing in amplitude to distinguish the dots, dashes and spaces. In Fig. 2, the arms *A* and *B* revolve clockwise, causing brushes to pass over resistances of the proper values to generate a sine wave type of e.m.f. from the battery, *C*. One complete revolution produces a complete cycle, and the disc, which is about four inches in diameter, is mounted vertically. Upon the shaft of the motor which drives the transmitting tape are mounted two brushes which rotate with the shaft and contact with the segments. This arrangement insures positive synchronism at all times between the movement of the tape and the applied battery so that the phase relation is under accurate control.

The amplitude of the semi-sinus of the alternating current produced is under complete control by the adjustable resistances *D* and *E*.

The tape transmitter used is of the Creed type, which is one of the best known. The method of course applies to any of the well-known types of automatic cable transmitters.

The cable operator proceeds as usual in transmitting traffic and has nothing new to learn in any of his operations.

In the photograph (Fig. 3) this transmitter is shown as set up and in operation in the laboratory.

It will be seen that this transmitter is not only a cable transmitter, but also a telegraph transmitter for any of the types of distortionless circuits of Class I, which includes radio and line radio circuits.

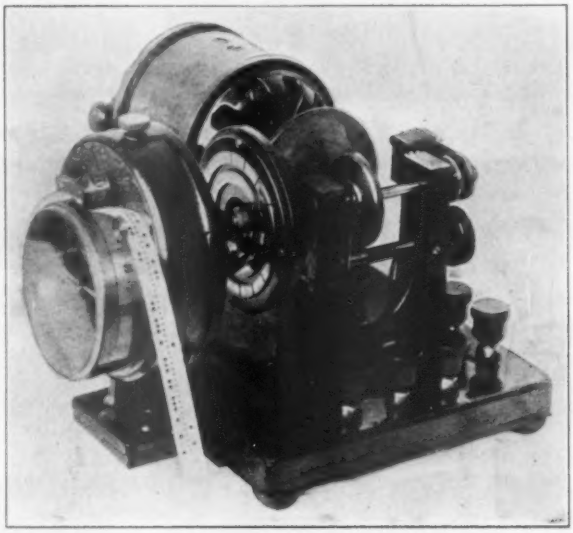
For such types of circuit we merely substitute for the variable resistances, *D* and *E*, of Fig. 2, suitable circuit arrangements by which the dot-and-dash contacts at the tape introduce different modulating frequencies instead of change of amplitude of the carrier frequency as is necessary in long cable. In space radio the change of amplitude method is objectionable on account of "fading," and in such circuits, other things being equal, we have a free hand to distinguish the signals by change of frequency.

In automatic telegraphy to-day we find a variety of forms of

transmitting tape, some of them quite complicated and difficult to keep in operation. In this universal transmitter, the simplest form of tape is adopted, *viz.*, a round perforation on the upper side of the feed holes for a dot and a similar perforation on the lower side for a dash.

This is tape reduced to its lowest terms, and provides a universal "tape language" for any type of circuit, whether space radio,

FIG. 3.



The Universal automatic telegraph transmitter for modulated alternating current applicable to radio land lines or submarine cables.

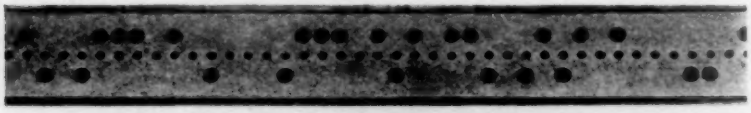
line radio or submarine cable. It also permits a certain free interchange of perforated tape between these circuits of different classes, whatever may be the actual speed in each.

THE PROPAGATION OF THE SIGNALS THROUGH THE CABLE.

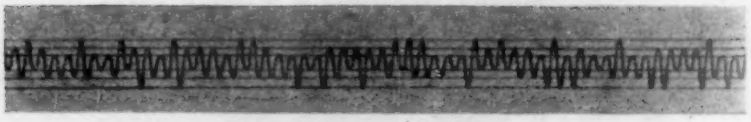
It should be noted that the transmitter described impresses upon the cable proper a continuous modulated wave of voltage or current of a definite fundamental frequency and wave-length. This wave is modulated at the zero phase of the resultant current flowing into the circuit, thereby changing the amplitude of the individual half cycles in three stages to represent dots, dashes and spaces. The relative values of these changes are under complete

control and are adjusted to suit the particular cable being used. Considering the cable alone, we know that the best condition for efficient transmission is fulfilled when each of the three amplitudes has the same value, and the case becomes the well-known example of power transmission by alternating current. In this limiting case, the speed of transmission of the then equal signals becomes greatly increased. The definition is always 100 per cent., and is

FIG. 4.



Transmitting tape.



Record of transmitted impulses.

Record of received impulses.

Record of received impulses rectified.

independent of the frequency, the voltage used, or the length of the cable. Such a condition would represent a message composed of a series of the letters A or N of the present cable alphabet joined without intermediate spaces.

We learn from this that, as far as the cable alone is concerned, the three amplitudes should differ only sufficiently to permit differentiation at the receiving end of the cable. Here the receiving apparatus enters the field as a controlling factor, so that the final adjustment of the transmitter is only found by trial and adjustment at both ends of the cable. The value of the space current requires particular attention, for although it is finally

eliminated from the record prepared for the eye, yet it has most important functions in keeping a whole chain of cables in operation from beginning to end, with perfect synchronism.

In the case of a single section of cable, we can adjust the transmitter so that the space current is of such a value as to just disappear by attenuation at the receiving end and still retain the advantages of comparatively large value of this current at the transmitting end for assisting in bridge balance and also in transmission through the cable itself.

In Fig. 4 is shown an example of the record of a message through an artificial cable in which the double amplitude of the space current is one-fifth of the double amplitude of the dash current, so that the ratio of space to dot and dash is at 1 : 3 : 5 in this particular case. The width of what is called "no man's land" in cable practice is one-fifth of the whole and the current occupying it serves to keep the receiving apparatus "alive" and to assist in overcoming the inertia of its moving parts.

THE VOLTAGE STRESS ALONG THE CABLE.

With an alternating current the law of distribution of voltage and current throughout the cable is entirely different than in the present cable practice.

In Fig. 5 is shown this distribution in the case of the new Seattle-Ketchikan cable, which data have been furnished by Major L. B. Bender, Chief of the Engineering and Research Division of the office of the Chief Signal Officer of the Army.

For a frequency of ten per second, for instance, we have

Frequency	=	10 ~
Speed in letters per minute	=	384
Wave-length = λ	=	802 nautical miles
Velocity of waves	=	8020 nautical miles per second
Time for one wave to traverse	=	0.1146 second

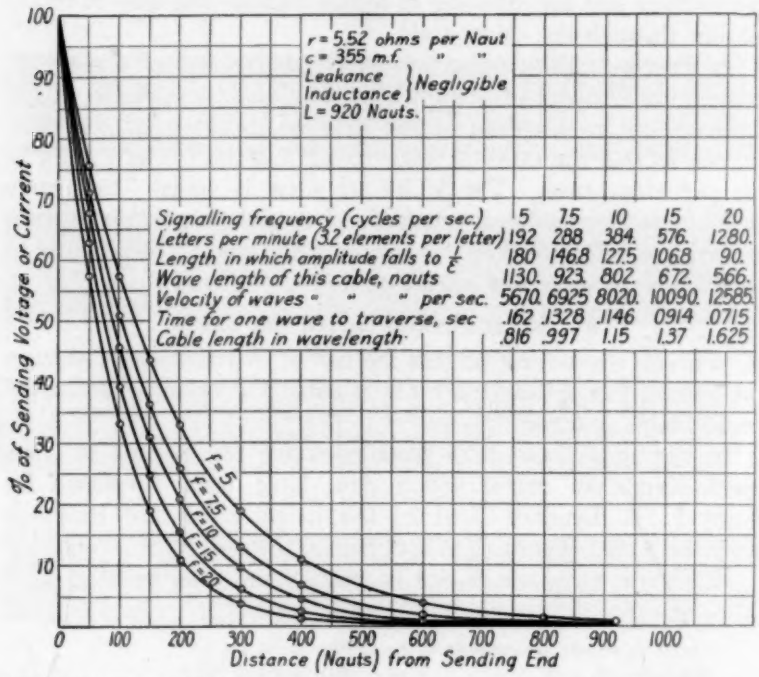
The voltage applied at the transmitting end of the cable rapidly decays according to the logarithmic law, until it has fallen to $\frac{1}{\varepsilon}$ of its initial value at only 127.5 nautical miles from shore. It has fallen to one-half of its value at ninety nautical miles from shore. The table and graphs of Fig. 5 show these data for frequencies of 5, 7.5, 10, 15 and 20 cycles per second.

Once we employ an alternating current for signalling, these calculations become simple enough, whereas with the present com-

bination of signals used on the cable there is no law of any kind, and we have to resort to the laborious method of analyzing each combination of signals as it passes through the cable by means of "curves of arrivals," a method first employed by Kelvin and later elaborated in Malcolm's classic work.

We may deduce the frequency of transmission required to

FIG. 5.



Current and voltage distribution, Seattle-Ketchikan cable, at frequencies 5 to 20 per second.

fulfil the condition that the cable itself shall be an exact multiple, odd or even, of the wave-length, or what is more important, a quarter wave-length.

We find approximately, in the case of the new Seattle-Ketchikan cable, as follows:

For $f = 4.24$, the cable length $= {}^3/_4\,\lambda$
$f = 11.7$, the cable length $= {}^5/_4\,\lambda$

Since the transmitter impresses all impulses at the zero phase, we may adjust the speed of the transmitting tape, other things

being equal, so that the wave will arrive at the receiving end of the cable at a node or anti-node of potential or current, corresponding to an even or odd multiple of $\frac{\lambda}{4}$.

We may look forward to an ocean cable office where each cable is equipped with a small panel switchboard, on which will be indicated continuously the voltage between the end of the cable and earth, the current impressed and the frequency and letters per minute being transmitted. These measuring instruments, of course, are already developed. The ammeter and voltmeter needles would take up an average position, and oscillate back and forth about this, indicating the dash-and-space voltage or current being transmitted. By transmitting a prepared "dash-tape," the engineer reads the maximum voltage and current used at any time.

INCREASED VOLTAGE DESIRABLE.

The voltage and current distribution curves shown in Fig. 5 draw attention to the desirability of increasing the transmitting voltage within safe limits. In present practice, all ocean cables operate at from fifty to eighty volts at the bridge apex, and much less than this upon the cable due to the capacity reactance of the large condensers in the arms of the bridge.

With an alternating current in the steady state, we know that the power impressed upon the cable varies directly with the *square* of the voltage used. We also see that in this case the voltage decays so rapidly that at a frequency as low as 10 per second it is reduced to one-half its value at about ninety nautical miles from shore. We may therefore regard the first ninety nautical miles of this cable as a "wave shute" used especially to launch the modulated a.c. wave upon its path through the real cable, being assured that no harmful voltage stress can possibly occur upon the deep-sea portion beyond. Indeed, we can afford, if necessary, to give special construction to this ninety nautical miles at each end of the cable, to enable us to employ any transmitting voltage found useful in practice.

The main reason why higher voltages have not been employed with the present system is not from fear of injuring cables as manufactured at present, but simply because only a very small increment of speed of signalling is obtained by such increase, due to the piling-up effects when using the present form of alphabet.

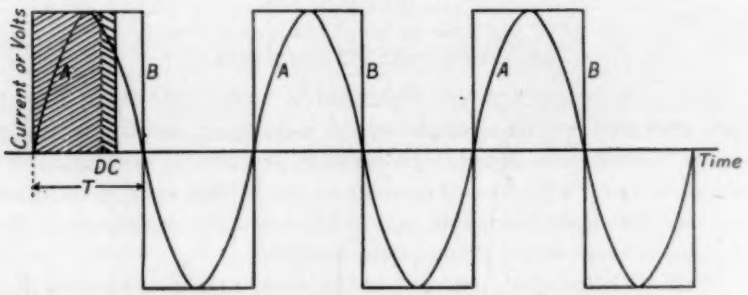
THE ALTERNATING CURRENT PRODUCES MAXIMUM RECEIVED AMPLITUDE.

There has been some discussion from time to time, when considering the alternating current system of cable signalling, of the relative amplitude and shape of the received signals over a long cable for different wave shapes at the transmitter. To fix the ideas, we may refer to the diagram in Fig. 6.

The curve *AAA* represents a simple alternating voltage or current wave impressed upon the cable itself at the transmitting end. *BBB* represents a battery reversal curve of the same frequency and maximum voltage or current.

In all long cables operated at high speed, we know that the Fourier series of odd harmonic waves which are required to

FIG. 6.



build up the square-topped wave *BBB* are absorbed in the cable and never reach the receiving end, in appreciable amount, as that only the fundamental wave has appreciable effect upon the receiver. It makes no material difference what the shape of the wave may be between *AAA* and *BBB*, provided only that it does not fall inside *AAA*.

Other things being equal, we can round off the corners of *BBB* in various ways as we please for other reasons, such as improving the bridge balance at the transmitting end, but the received signals in each case will be to all appearances the same.

The areas of the corners of *BBB* over and above *AAA* are made up, as stated, of a series of alternating waves which are harmonics of the fundamental wave of *BBB*. All these theoretical alternating e.m.f.'s are in operation at the transmitter and each sends its own current into the cable independently of the others. These harmonics have appreciable amplitude at the transmitting

end but soon decay in the cable itself and have no significant effect at the receiver.

The relative charges measured in coulombs in sending a single semi-cycle of *AAA* or *BBB* into the cable may be measured by the areas of the voltage wave impressed. These areas are as about .6 to 1. This extra charge of about .4 of the maximum, or .24 of the semi-sinus takes no practical part in signalling but does serious harm because we must get rid of it at the transmitting end to bring the cable back to a neutral condition so we can send the succeeding signal. This effect is multiplied when we send any one of the five letters, H, I, M, O or S. In getting rid of this superfluous charge at the transmitting end of the cable it is found desirable to disconnect the battery entirely after about 75 per cent. of the whole time of the signals and connect the cable directly to earth. These idle harmonics are then discharged to earth during the last quarter of the time of the signal and this discharge is shown in the spark at the instant of disconnecting the battery by opening the key. The illustration in Fig. 6 is, therefore, a theoretical assumption and cannot be carried out in practice.

In fact, we see that the area of *B* is not the area which we use in signalling nor indeed is the area indicated by cutting off one-quarter of the whole as at *C*, for during this last quarter time of the signal we have connected the cable to earth and a considerable portion of the charge already sent into the cable has been discharged again, reducing the area to some lesser value indicated by the dotted ordinate at *D*.

The wave *A* employs the whole time of the signal usefully and efficiently and there is no need of mutilating the signal as in present practice.

Again the assumption above is theoretical for the reason that a voltage wave like *BBB* must be impressed upon the cable at the apex of the bridge and in present practice the bridge arms require large condensers of 60 m.f. or more.

These condensers of course materially alter the shape of the wave *BBB* and the tops of the wave are no longer horizontal but also decay from the full battery voltage at the beginning of each signal to some lesser value at the instants of cut-off at three-quarters of the time of the signal. The rate of this particular decay depends upon the size of the condenser, so that here also the required transmitting condensers operate to reduce the area of

the battery effect upon the cable itself. Enough has been said to show that whatever the circuit arrangements used in present practice, a simple alternating current produces a greater amplitude of received signals than battery reversals of the same frequency and maximum voltage value. This merely means that it delivers more energy at the receiving end of the cable and more energy means more speed. This is the main reason for using the *AAA* type of wave for power transmission.

Malcolm has worked out a great variety of combinations of present cable signals by computing their "curves of arrival." The extreme distortion in long cables is such that the effects of what is called "tailing" of the signals produce in certain combinations, such as in the words "banana cancer," for instance, changes in shape of certain letters of "cancer" traceable even back to the word "banana" immediately preceding. In other words, we must know the history of the cable immediately preceding a signal to predict its exact form in any particular case.

When we adopt a modulated alternating current form of alphabet, although of course we still have certain minimum of transient effects, the physics of the whole process becomes greatly simplified.

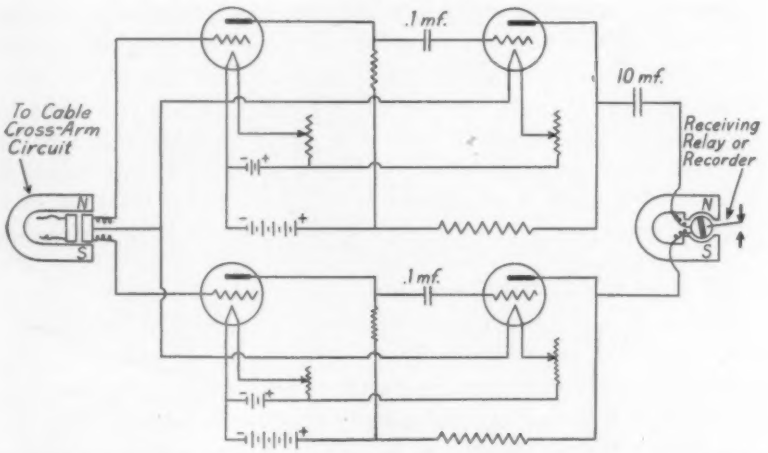
AMPLIFICATION BY ELECTRON TUBES.

The phenomenal development of broadcasting over great distances is made possible by the use of amplification, often in several stages, of the extremely attenuated signals of speech or music, which arrive at the receiving antenna. The electron tube, used as an amplifier, is basically responsible for permitting the handling of these complicated electromagnetic waves, attenuated almost beyond measurement. In the key plan (Fig. 1) this powerful instrumentality, which has done such wonders for broadcasting, should logically take its place as one of the vital steps in the reception of long submarine cable signals. Indeed, during the last few years, efforts have been made to apply the electron tube as an amplifier to the signals received over an ocean cable, but thus far without practical success. A discussion of the reasons for this failure is beyond the limits of the present paper, but it is partly due to the faulty design of the alphabet itself as used at present.

Enough has been said to indicate that the cable engineering of the near future will include amplification, probably in several

stages, of the sub-audio signals received. In this connection, certain preliminary experimental work has been accomplished already in the laboratory. The plan adopted employs a method of coupling the receiving circuit, containing the amplifying tubes, to the cable circuit itself, which may be described as "regenerative coupling." When one attempts to couple a tube receiving circuit to the cable, either directly, inductively, or electrostatically, difficulties are experienced. A long ocean cable, with practically no inductance or

FIG. 7.



leakance, and a capacity of the order of a thousand m.f. is not adapted to the usual methods of coupling applied in radio engineering. For this reason the experiments thus far conducted have coupled the cable circuit to the amplifier circuits containing the tubes, by means of an adaptation of the regular standard type of d'Arsonval moving coil now universally employed in all cable receiving instruments.

In Fig. 7, this method of coupling is shown as well as the circuit diagram used in two stages of sub-audio amplification. The application of the radio features of the diagram will be readily understood, and needs no further comment.

The regenerative coupling employed, as indicated at the left of the diagram, requires a word of explanation. In radio telephony the advantages of loose coupling are well recognized as the energy is transferred from one circuit to another without reaction between the two circuits. In like manner the long cable

circuit should be separated from the amplifying circuit by a type of coupling which will prevent reactions between the two. The method indicated above is to employ the standard d'Arsonval coil, with a second winding, so that the second coil acts as a generator of electromotive force, due to the motion of both caused by the received cable current in the first coil. It is the practice at present to have two windings on this coil, in order to use this second winding for certain corrective effects for increasing the definition of certain letters of the present alphabet, so that this type of regenerative coupling in the first instance has been tried by taking the same type of coil as now exists in cable receiving apparatus, and using the second winding as a source of electromotive force which in turn changes the potential on the grid of the tubes as indicated in the diagram. The principle involved in this type of coupling is to produce an entirely new source of electromotive force. This method of coupling enables us to use the tube as it is designed to be used as a potential instrument. To indicate that there is no direct inductive effect between the two windings, the coils, when clamped in a fixed position, should not affect the amplifier by any current received from the cable through the first coil. Since the coil in this case is free from all so-called gear, usually carried, its inertia is reduced to a minimum and it possesses a frequency response far beyond any required at present for cable signalling. Furthermore, the sensitivity of the electron tubes to minute grid potential changes is so great that a movement of the coil, not perceptible even with a reading glass, furnishes for the imput circuit of the tube a pure signal wave, regenerated, and eliminates effectively the large group of stray high-frequency disturbances which have been shown to exist in many submarine cables.

The final solution of this particular problem of amplification will be made by radio engineering methods modified to suit the low frequencies involved, and it will furnish a compact amplifying unit for the cable station which will assume a rôle comparable with its present importance in broadcasting.

THE BRUCE CABLE RELAY USING ELECTRON TUBES FOR CONTACT MAKING.

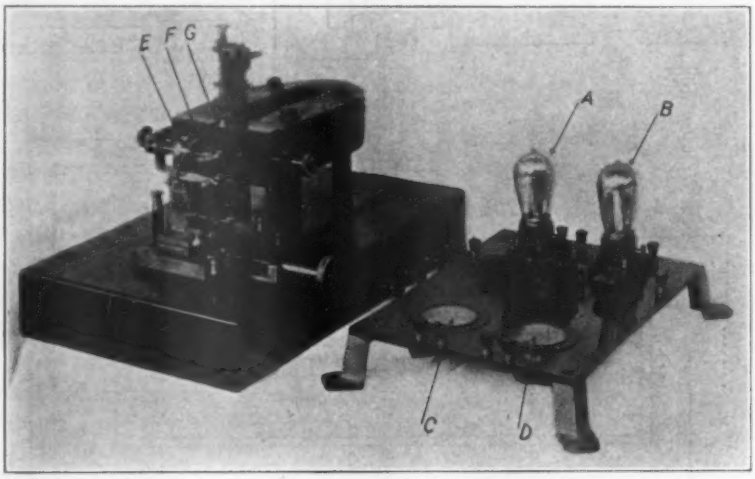
In all previous cable relays the required contacts are made by the actual closing of a metallic circuit to permit the action of a current operated device of some kind.

The Bruce type of cable relay introduces for the first time in cable practice the principle of potential contacts by using the electron tube, which is essentially a potentially operated instrument.

In Fig. 8 is shown a photograph of this relay as used in these experiments.

A and *B* are two five-watt electron tubes, *C* and *D* are milliammeters in series with the plate circuit of each tube. *E* is a

FIG. 8.



Bruce cable relay using vacuum tubes for rectifying modulated alternating current signals.

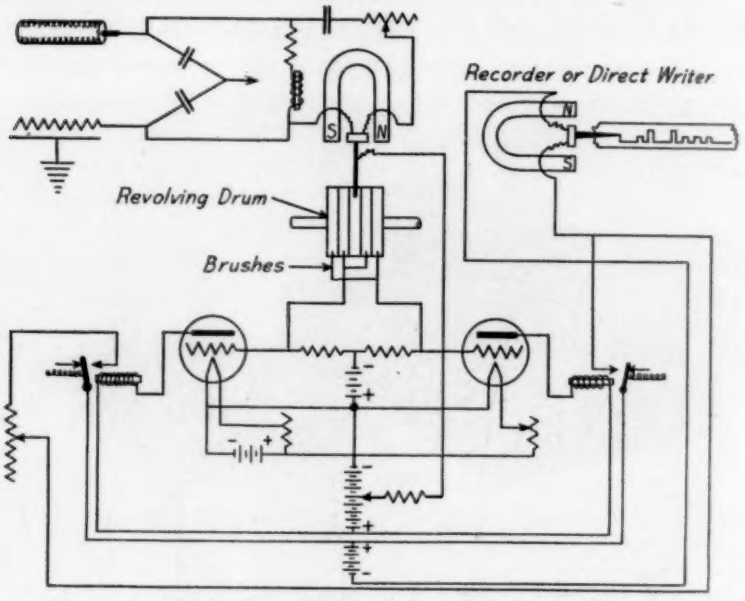
revolving drum 1½ inches in diameter, consisting of a metal surface centrally located, on either side of which, and insulated from, are two similar metal surfaces insulated from each other by thin mica insulation.

A usual relay tongue *F* is employed and is capable of contacting with the surfaces above described. The movable coil *G* in its excursions, corresponding to the different amplitudes of the received wave, contacts with the surfaces corresponding to the dots, dashes and spaces.

In Fig. 9 is shown one type of circuit used. It will be seen that for the first time two entirely independent ratios of dot-to-dash records are provided, and these ratios are adjustable so that the receiving operator can form the signals to suit his particular fancy.

An important point to note, in accordance with the key plan (Fig. 1), is that the relay serves to detect or rectify the output wave from the cable, and detection or rectification is an essential step in the reception of all radio messages in preparing them for final interpretation by the ear. It appears that rectification is a

FIG. 9.



Bruce method of producing rectified signals for modulated a. c. cable systems.

most desirable and important step also in preparing cable messages for reception by the eye.

To insure through working it is necessary to establish repeating stations at intermediate points. Obviously these repeated signals should be of exactly the same wave form as the initial wave transmitted. The unbalance of the duplex bridge will, to a certain extent, affect the incoming wave form. The alternating current system lends itself admirably to regeneration and retransmission in a simple manner.

In fact, in the case of a long chain of cables linked together, as is usual, for instance, in operating from London to Cape Town, or to Australia, with the alternating current system, each of the receiver coils of the cable magnifiers and relays becomes a tor-

sional pendulum, all vibrating continuously and isochronously for dots, dashes and spaces and each delayed behind the preceding one by the time required for the particular frequency wave being transmitted to traverse the section of cable immediately preceding its station.

PRINTER SYSTEMS.

Of course the desirable thing in telegraphy is to produce a final record printed on a receiving tape which is pasted directly upon a delivery blank, or better, a page printed so that the message is ready for delivery to the public as it comes from the receiving instruments.

On land lines we have such printers operated multiplex, usually upon the five-unit code system where each letter itself transmitted requires five units of time.

Such a plan for ocean cables is inefficient for the reason that it sacrifices speed, since the average letter and its space at present requires but 3.67 units of time. It is inefficient also because, in making up the combinations of elemental signals to produce the different letters, no attempt is made to introduce the continuous alternating current principle, including the space between letters and words, so that we find the same inherent difficulties in transmitting and differentiating these combinations of signals as was noted above in the present cable alphabet, and for the same reasons. Printer systems of this type could be improved by applying the modulated alternating current principle.

These difficulties can be completely overcome if we can cause the rectified record shown in Fig. 4 to operate directly a printer of the Creed type. The adaptation of this printer in this manner is now under development for ocean cable operation.

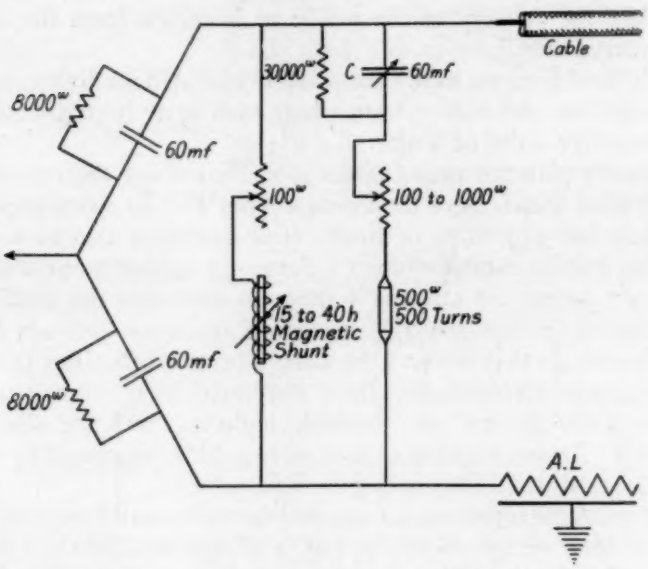
This type of rectified record has been submitted to expert operators of the Signal Corps stationed in different parts of the United States, in the Philippines and in the Hawaiian Islands, and it has been universally approved as far superior to the usual record where the dots and dashes are recorded in a single horizontal line.

THE PRESENT CIRCUIT ARRANGEMENTS FOR RECEIVING LONG CABLE SIGNALS.

In Fig. 10 is shown the general arrangement of receiving circuits now employed in the cable duplex. We note that there has been introduced across the galvanometer arm of the

Wheatstone Bridge, a shunt arrangement, comprising in particular what is called a "magnetic shunt," which consists essentially of a large, low-resistance inductance, made by a few turns of wire wound about a large mass of high permeability iron. There is in series in the galvanometer arm proper of the bridge the condenser, *C*, which usually has a capacity of about 60 m.f. This condenser also is provided with a condenser leak of about

FIG. 10.



30,000 ohms. The recorder coil, as indicated, has reached practically a standard value of 500 to 600 turns, which will approximate 500 to 600 ohms, with negligible inductance. The values of these elements are the result of long years of effort to increase the definition of the different letters of the alphabet as they appear in the incoming signals. It may be stated, in general, that the function of the magnetic shunt is twofold. Its very large inductance, sometimes reaching the value of forty or more henrys, is employed to bring about a degree of resonance in the closed loop circuit which includes the condenser, *C*, ohmic resistances and recorder coil. This particular loop circuit functions, when properly adjusted, to build up by the principles of resonance the

amplitude of certain letters according to the principles of electrical tuning.

As already pointed out, the present cable alphabet may be divided into certain groups of letters, which will assist us to see more clearly the very complex problem, which is presented in improving the definition of cable signals.

GROUP I. THE LETTERS A, C, K, N, R.

These five letters of the alphabet are received with maximum definition regardless of the shape of the impulses sent, *e.g.*, whether the impulses are square-topped or otherwise. A long cable itself may therefore be said to be a most efficient electrical "filter." In the loop circuit in the figure, if the problem were to receive only this group of five letters, the engineer would know immediately how to proceed. For instance, if the receiving condenser, *C*, was set for 60 m.f., he could immediately determine what value of inductance the magnetic shunt should have at any particular speed of signalling. Of course, for these very low frequencies, the apparatus itself takes on sizes very different from those in radio, but the principles of operation are identical.

GROUP II. THE LETTERS H, I, M, O, S.

In this group, which also contains five letters, we find that the present cable alphabet employs individual pulses of the same polarity consecutively.

The two letters, E and T, are not included in the above groups for the technical reason that only a semi-sinus is used in each and the engineering unit is the complete cycle.

The other fourteen letters of the alphabet fall into a group which may be analyzed into an equivalent alternating current of a fundamental frequency, lying between these, so that a table of the alphabet could be prepared in which each letter would be classified and described by the fundamental frequency employed in transmitting it.

The electrical loop circuit above has to receive also the third group of variable frequencies lying between one and two. This greatly complicates the engineering problem involved, and has led to a large variety of circuit arrangements, which have been worked out through the years to fit each particular individual cable, with the general plan of bringing the average legibility of all the signals up to the highest possible level. This solution is,

of course, a compromise because manifestly the ideal alphabet would be one in which the legibility of all letters is the same.

On this view, it is seen that the Group II letters, namely, H, I, M, O, S, have during the half century of ocean cable working been responsible for pulling down the average traffic rate of all ocean cables to their speed level, and it would be interesting to estimate the price which the world has had to pay in all these years as a tribute to these badly designed letters.

The second function of the magnetic shunt is one of furnishing a low resistance path to earth, particularly for Group II letters, and to a lesser extent, of course, for the group of fourteen letters. Otherwise, definition would be impossible.

A study of the present cable alphabet discloses the remarkable fact, entirely independent of the method of sending individual elements, that the basic assignment of these combinations of elements to the letters themselves is not an assignment suited to the English language. To illustrate, the vowel letter "O," which in English telegraph practice stands second in order of frequency of usage by actual count of ten thousand letters, is assigned three dashes, which by the cable alphabet requires *four* units of time in transmission, whereas the letter "M," which in actual frequency of usage occurs less than one-third as often as "O," is assigned only two dashes, requiring three units of time. The simple transposition of these two letters should in itself result in a saving of thousands of dollars a year to the cable companies.

THE DUPLEX BRIDGE BALANCE.

At the present time, all important ocean cables are operated duplex by the Wheatstone Bridge method. To give even a faint idea of the immense amount of effort and skill which has been devoted to the development of the Wheatstone Bridge, to enable duplex working on ocean cables, it may be said at the outset that no theorist could have ever predicted that what is now being done daily in this direction could ever be accomplished. When we realize that in this method, due to the great attenuation of the signals in passing through ocean cables, the magnitude of the input signals is fifteen to twenty thousand times greater than the output signals, it is easily understood why the balance becomes such a limiting factor. Although the duplex bridge has these permanent disadvantages, necessarily inherent in the case, we are not yet

ready to abandon this method. In other words, a change of plan by which cable messages would be sent all one way on one cable and all the other way on a second cable, or at different times on the same cable, has basic advantages which must be considered in individual cases, based on the traffic situation and many other things.

In the attempts which have been made continuously to increase the speed of duplex cable operation, we are always confronted with two antagonistic factors. The more sensitive we make our receiving apparatus for the signals themselves, obviously, the more they respond also to bridge unbalance, with the result that for many years we have had a number of cable receiving instruments which possess a sensitivity far beyond any possible chance of using them. In addition, as will be referred to presently, we have recently discovered that the disturbing elements at each end of a submarine cable are far more complicated than engineers ever realized, until research with the electron tube disclosed them.

In the last analysis it is always the opening and closing of the transmitter key which produces the final kick or " jar " in the balance. This is not surprising when we remember that, from an electrical standpoint, nothing can be done to a circuit more severe than suddenly to introduce an infinite resistance into it.

However, since there is an appreciable spark or arc at the instant of opening the battery transmitter circuit, this discharge from the cable controls to a greater or lesser degree the character of the break; but the exact influence of this is not so easy to predict, for, though it is probable that the current dies away quicker with a sudden break than it does with a very slow one, which permits the arc to remain for some time, yet it is not proved certainly, for the more rapidly the break is made the faster the resistance increases, and therefore, probably, the rate of change of current, and with it the counter e.m.f., increases. An increased e.m.f. can bridge a longer gap, but a longer gap may be made in the same time that a short one is, with a less velocity at the break. So it appears that these two considerations counteract each other, and it all depends upon which has the greater influence.

This teaches us the fundamental necessity for removing from the circuit any make and break at the transmitter and substituting

the smooth continuous wave form of the modulated alternating current.

With this change, as careful tests have shown, the balance of the bridge may be greatly improved, which means, of course, increase of speed.

The development of the modern artificial line for simulating the conditions of the cable has required a large amount of patient and careful work, extending over a number of years. As soon as any form of break, with its consequent spark or arc, is removed from the transmitter circuit, and a continuous modulated alternating current is substituted, the artificial line can represent more faithfully the action of the current flowing in the real cable, and its construction may be simplified.

The present form of square-topped signals, when combined to make up letters and words, causes a broken and irregular form of current to enter the apex of the bridge, which precludes the possibility of measuring the ordinary quantities, such as voltage, current, impedance and phase-angle of the different arms of the bridge circuit. This is extremely unsatisfactory from an engineering standpoint, and leaves us only the method of trial and correction upon which to depend.

Since each elemental signal is earthed during one-quarter of the whole time of the signal, this means that, of necessity, the cable is entirely disconnected from the battery at both ends for a period aggregating not less than six hours a day. These six hours are required to drain the cable of superfluous electrical charge in order that the plant may operate during the remaining eighteen hours.

HISTORICAL.

On September 13, 1918, by authority of the President, the State Department appointed a Technical Committee, known as the State Department Special Committee on Cables. The Committee was requested "to examine, experiment, and report upon any methods or improvements looking to increased efficiency in the operation of submarine cables, with special reference to the Trans-Pacific Cables." This committee was composed of the following distinguished scientists: Gano Dunn, Chairman; Dr. Arthur E. Kennelly, Dr. Frank B. Jewett, Members of the National Academy of Sciences; and Bancroft Gherardi, Past Vice-president of the American Institute of Electrical Engineers. Certain funds were

provided by the War and Navy Departments for the use of the Committee in experimental work.

Through the coöperation of the cable companies in placing the Atlantic cables at the disposal of this committee for experimental purposes, very valuable technical data were obtained, disclosing a large variety of electrical disturbances present in submarine cables which had not been suspected before. These results were made possible by the use of the electron tube as an amplifier.

Recently the American Telephone and Telegraph Company has developed a new alloy known as "permalloy," which possesses remarkable magnetic properties at low magnetizing forces, making it particularly adaptable for use in the manufacture of submarine cables. A section of cable using this alloy has been already manufactured.

In 1922, the Signal Corps of the Army took steps to have allotted from its funds an amount sufficient to cover a fundamental investigation by the National Bureau of Standards, looking to a substitute for gutta percha in the manufacture of submarine cables. This investigation is still in progress.

SUMMARY.

(1) After over half a century of experience with ocean cables, during which time every refinement has been introduced that skill and ingenuity can devise, we are at present entering a new phase of cable development which will give ultimately a speed and accuracy unthought of at present.

(2) The basic engineering principles and instrumentalities, which have made radio the marvel of the age, will be adapted and applied to the sub-audio band of frequencies wherein principally lies ocean cable practice.

(3) Signal Corps developmental work in connection with the new Seattle-Ketchikan cable, carried out during the past year at the laboratory of William M. Bruce, Jr., at Springfield, Ohio, in accordance with a key plan based upon radio engineering principles applied to ocean cables, has resulted already in marked progress.

(4) A universal automatic telegraph transmitter, applicable to radio, land lines and submarine cables, has been developed and tested over an artificial cable in the laboratory.

(5) An improved form of rectified received record has been devised and tested.

(6) With funds furnished by the Signal Corps of the Army, the National Bureau of Standards has been engaged for some time in searching for a substitute for gutta percha. The construction of ocean cables with distributed inductance by means of the recently developed material, "permalloy," will furnish a new impetus to cable manufacture and will contribute to increased speeds and multiplex operation.

(7) As in radio, the electron vacuum tube will play a dominating rôle in this new development. Amplification by several stages of the received cable signals, as in the present radio broadcasting service, will open up an entirely new range of cable efficiency. With properly designed signals, this amplification has been shown already in the laboratory to be practicable.

(8) There is no real social or economic conflict between ocean cable and radio telegraphy. The one is essentially a point-to-point two-way service between individuals, the other, at present, at least, is essentially a broadcasting one-way service, depending upon mass appeal. Each has its own natural field of usefulness in the development of world traffic. The logic of events will eventually place each service in its proper sphere.

(9) Economically, a cable company is no more than a factory, where the output for sale to the public consists of sheets of paper upon which are words and sentences.

(10) This type of factory is unique in that the outstanding items of annual expense are the interest on the cost of the cable, the replacement sinking fund, and the maintenance of a cable ship as insurance against interruptions. Unlike the ordinary factory, there is no deterioration of the plant due to wear and tear of the electrical signals produced, and the cost of the electrical energy required to operate this factory is a negligible quantity.

WASHINGTON, D. C.,
April 22, 1924.

THE velocity of alpha particles at the instant they leave RaC is that corresponding to the modest temperature of 5,800,000° C. (*Phil. Mag.*, Feb., 1924, p. 430). G. F. S.

THE SCATTERING OF X-RAYS.*

BY

ARTHUR H. COMPTON, Ph.D.

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THE present paper will be confined to a discussion of some of the points which present to us a revolutionary change in our ideas regarding the process of scattering of electromagnetic waves. No attempt will be made to describe the great amount of experimental and theoretical work which has been done on the subject.

The theoretical researches of J. J. Thomson and the experimental work of Barkla and others had shown so striking an agreement between experiment and the theory of the scattering of X-rays based upon the usual electrodynamics that scattering has been classed with dispersion and interference as a phenomenon that is completely explicable according to our classical ideas. Within the past two years, however, scattering phenomena have been observed which are so directly contrary to the predictions of the usual electrodynamics that we apparently have to reverse our attitude almost completely. We thought we could explain the scattering of X-rays on the assumption that radiation proceeds in spherical waves, spreading in all directions in space. We now find that to retain this assumption, if our recent results are correct, we must abandon both the principle of the conservation of momentum and the principle of the conservation of energy—a hard choice, indeed; but that our observations are explained simply if we are willing to imagine the rays as consisting of discrete quanta proceeding in definite directions.

Just as a piece of paper held in the sunlight becomes a source of scattered light, so a piece of paraffin placed in the path of a beam of X-rays becomes itself a source of scattered X-rays. These rays may be examined with a fluoroscope, a photographic plate or an ionization chamber in the same manner as the primary beam. Just as the light coming from zinc sulphide exposed to sunlight consists of a mixture of fluorescent and scattered light,

* Based on a paper read before Section B of the American Association for the Advancement of Science, Dec. 28, 1923.

so, in general, the rays from a radiator placed in a beam of X-rays consist of a mixture of fluorescent and scattered rays. There are the fluorescent *K* and *L* radiations, X-rays whose wave-length is characteristic of the elements from which they come, and truly scattered rays whose wave-length is independent of the material of the radiator, but is dependent upon the wave-length of the primary rays. From the heavier elements the fluorescent rays usually predominate, but from the lighter elements under ordinary conditions the scattered rays only are present in the secondary beam. It is these truly scattered rays with which we are now concerned.

The classical electron theory has a very straightforward explanation of the scattering of radiation. When an electromagnetic wave traverses matter, the electric vector of the wave gives each electron in the matter an acceleration. In virtue of this acceleration these electrons themselves radiate energy. The frequency of the forced oscillations of the electrons will have to be that of the incident wave, and the frequency of the reradiated waves will, of course, be the same as that of the electrons which produce them. The frequency, and hence the wave-length, of the scattered rays is thus necessarily the same as that of the primary X-rays.

This theory of the scattering of X-rays was first developed in detail by J. J. Thomson.[1] Knowing the charge and mass of the electron, its acceleration when traversed by a wave of known intensity can be calculated, and hence the amount of scattered energy which it will reradiate can be estimated. You will remember that it was by comparing the results of such a calculation with the experimental value of the intensity of the scattered X-rays that Barkla first reached the conclusion that the number of electrons in an atom is equal to about half the atomic weight.[2] The agreement of this estimate with the atomic number, as determined by later methods, indicates that the classical theory as developed by Thomson is at least in approximate accord with the facts.[3]

The earliest experiments on secondary X-rays and γ-rays showed, however, a difference in the penetrating power of the

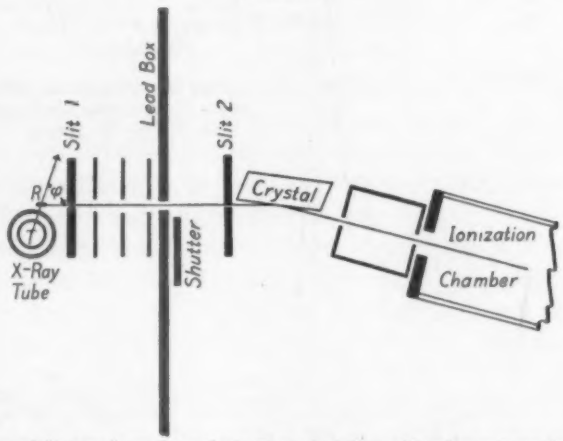
[1] J. J. Thomson, "Conduction of Electricity through Gases," 2nd Ed., p. 321 *et seq.*

[2] C. G. Barkla, *Phil. Mag.*, 7, 543, 1904; 21, 648, 1911.

[3] *Cf.* also C. W. Hewlett, *Phys. Rev.*, 19, 266, 1922.

primary and the secondary rays. In the case of X-rays, Barkla and his collaborators showed that the secondary rays from many of the elements consisted largely of fluorescent radiations characteristic of the radiating element, and that it was the presence of these softer rays which was chiefly responsible for the greater absorption of the secondary rays. When later experiments showed a measurable difference in penetration, even in the case of light elements such as carbon, from which no fluorescent K or L radiation appears, it was only natural to ascribe this difference to a new type of fluorescent radiation, similar to the K and L types,

FIG. 1.



The spectrum of the rays from the radiator R, at an angle φ with primary beam is investigated.

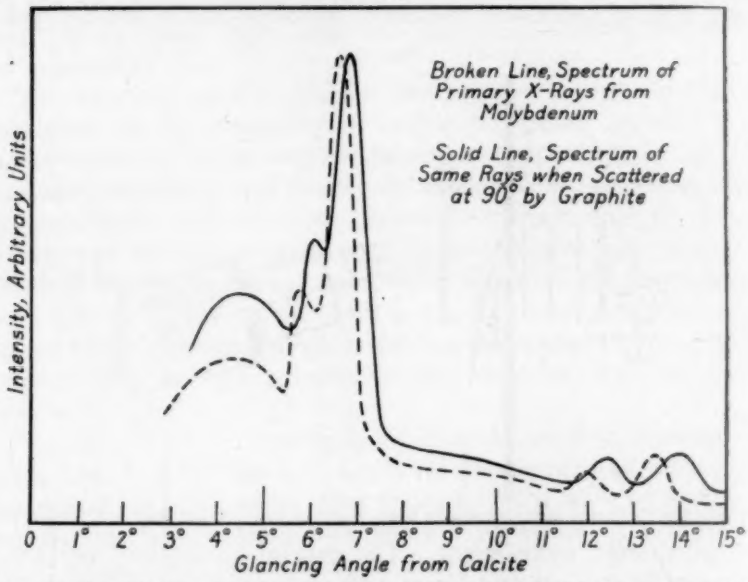
but of shorter wave-length. The careful absorption measurements of Richtmyer and Grant and of Hewlett failed, however, to show any critical absorption limit for these assumed "J" radiations similar to those corresponding to the K and L radiations. Moreover, direct spectroscopic observations by Duane and Shimizu failed to reveal the existence of any spectrum lines under the conditions for which the supposed "J" rays should appear. It thus became evident that the softening of the secondary X-rays from the lighter elements was due to a different kind of process than the softening of the secondary rays from heavy elements where fluorescent X-rays are present.

It was at this stage, about two years ago, that I began the spectroscopic examination of the scattered rays from light elements. The reason that such experiments had not been performed

before was doubtless because the low intensity of the scattered rays makes their spectroscopic examination relatively much more difficult than that of the primary X-rays. Instead of showing scattered lines of the same wave-length as the primary rays, these spectra revealed lines in the secondary rays corresponding to those in the primary beam, but with each line displaced slightly toward the longer wave-lengths.

A diagram of the apparatus employed, such as is shown in

FIG. 2.


Broken Line, Spectrum of Primary X-Rays from Molybdenum
Solid Line, Spectrum of Same Rays when Scattered at 90° by Graphite
Intensity, Arbitrary Units
0 1° 2° 3° 4° 5° 6° 7° 8° 9° 10° 11° 12° 13° 14° 15°
Glancing Angle from Calcite

Spectrum of molybdenum X-rays scattered by graphite compared with the spectrum of the primary X-rays, showing an increase in wave-length of the scattered rays.

Fig. 1, may help in understanding the significance of the result. There X-rays proceed from the molybdenum target T of the X-ray tube to the carbon radiator R, and are thence scattered at 90° with the primary beam through the slits 1 and 2 to the crystal of the Bragg spectrometer. We thus measure the wave-length of the X-rays that have been scattered at an angle of 90°. This angle may be altered by shifting the radiator and the X-ray tube, and the spectrum of the primary beam may be obtained by merely shifting the X-ray tube, without altering the slits or the crystal.

In Fig. 2 are shown complete spectra of both the primary and the scattered beam. Here the broken line represents the first and

second order spectra of the direct rays, and the solid line, drawn of course on a much larger scale, represents the spectrum of the scattered rays obtained under the same conditions. Though the difference between the first order spectra is not great, in the second order the difference in wave-length between the primary and the scattered lines is readily measurable. It is clear from this spectrum that the secondary X-rays do not have a fixed wave-length characteristic of the radiator as do fluorescent rays, but that each line in the secondary spectrum corresponds to a line of the primary spectrum.

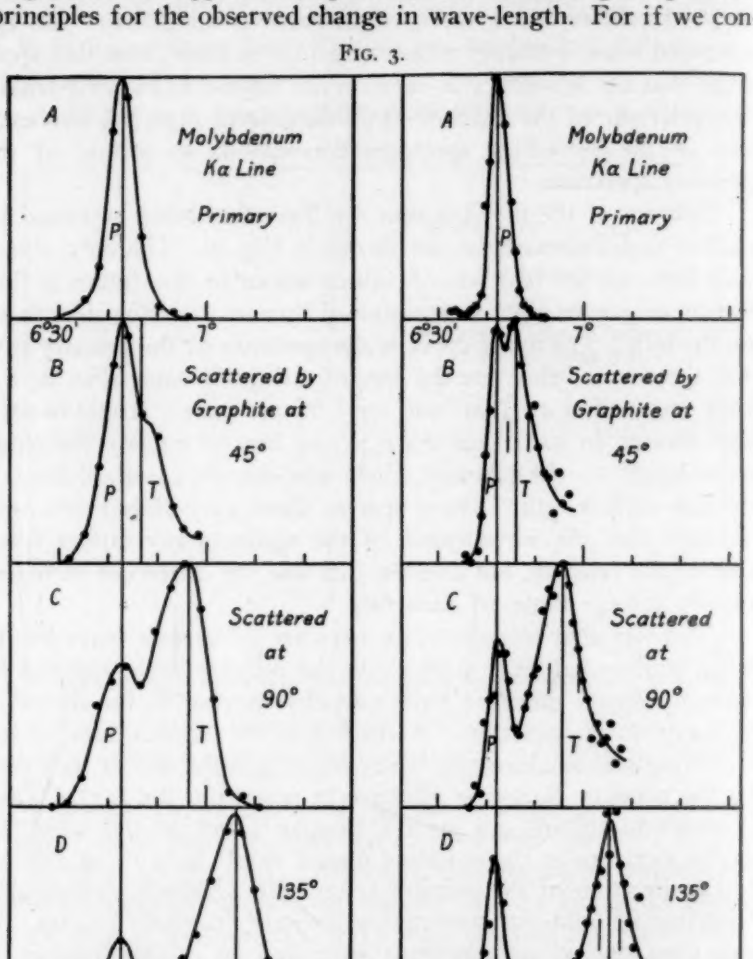
Spectra of the molybdenum $K\alpha$ line after being scattered by carbon at different angles are shown in Fig. 3. The only difference between the two sets of values shown in this figure is that the curves on the right were obtained by narrower slits than those on the left. The upper curve is the spectrum of the primary ray, and the curves below are the spectra, using the same slits, of the rays scattered at 45°, 90° and 135°, respectively. It will be seen that though in each case there is one line of exactly the same wave-length as the primary, there also occurs a second line of greater wave-length. These spectra show very clearly not only the fact that the wave-length of the scattered ray differs from that of the primary, but also the fact that the difference increases rapidly at large angles of scattering.

The fact that the secondary rays are of greater wave-length when scattered at large angles with the primary beam suggests at once a Doppler effect as from particles moving in the direction of the primary radiation. According to the classical idea of the scattering process, however, every electron in the matter traversed by the primary X-rays is effective in scattering the rays. Thus in order to account for such a Doppler effect on this view, all of the electrons in the radiating matter would have to be moving in the direction of the primary beam with a velocity comparable with that of light—an assumption obviously contrary to fact. It was clear that if any electrons were moving in this manner, it was only a very small fraction of the whole number in the scattering material, and that it must be this small fraction which was responsible for the scattering. The idea thus presents itself that an electron, if it scatters at all, scatters a complete quantum of the incident radiation; for thus the number of electrons which

move forward would just be equal to the number of scattered quanta.

This suggestion that each quantum of X-rays is scattered by a single electron supplies a simple means of accounting on quantum principles for the observed change in wave-length. For if we con-

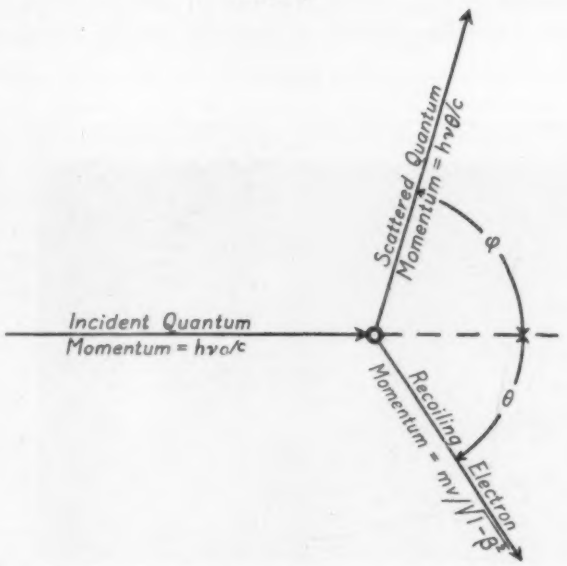
FIG. 3.



When an X-ray spectrum line is scattered, it is broken up into two lines, one of unmodified wave-length P and a line T whose wave-length is increased by the amount $h/mc \times (1-\cos\varphi)$.

sider the primary rays to proceed in quanta so definitely directed that they can be scattered by individual electrons, along with their energy $h\nu$ they will carry momentum $h\nu/c$. The scattered quantum, however, proceeding in a different direction from the primary, carries with it a different momentum. Thus by the principle of the conservation of momentum, the electron which scatters the ray must recoil with a momentum equal to the vector difference

FIG. 4.



When an X-ray quantum is scattered by an electron at an angle φ, the electron recoils at an angle θ, removing some of the energy from the quantum and hence reducing its frequency.

between that of the primary and that of the scattered quanta (Fig. 4). But the energy of this recoiling electron is taken from that of the primary quantum, leaving a scattered quantum which has less energy and hence a lower frequency than has the primary quantum. A simple calculation on this basis shows that the scattered ray is of greater wave-length than the primary ray by the amount

$$\lambda^1 - \lambda = \delta\lambda = \frac{h}{mc}\left(1 - \cos\varphi\right),$$

where h is Planck's constant, m the mass of the electron, c is the velocity of the light and φ is the angle between the primary and

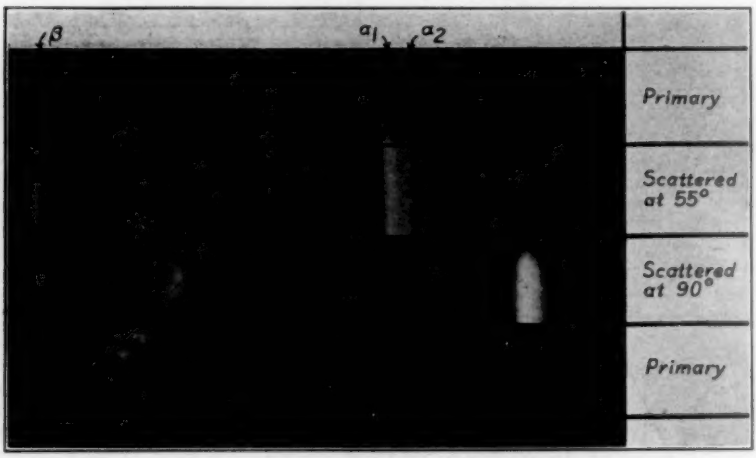
the scattered beams. The electron which scatters this quantum should recoil with an energy which is to a close approximation,

$$E_r = h\nu \cdot \frac{h}{mc\lambda} \cos^2\theta$$

where ν and λ are the frequency and wave-length of the primary wave, and θ is the angle between the primary beam and the direction of recoil of the electron.[4]

These results are subject to direct experimental test. In the spectra shown in Fig. 3, the position of the line T is calculated in each case from the theoretical formula for the change in wave-

FIG. 5



Spectrum of K-rays from molybdenum, scattered from paraffine and reflected from calcite (P. A. Ross).

length. As you can see, in every case these lines fall within experimental error at the maximum of the modified line.

These ionization spectra are completely confirmed by the beautiful photographic spectra obtained by P. A. Ross, using prolonged exposures as great as 250 hours. Fig. 5 shows two of his hitherto unpublished spectra which he has been so kind as to loan me for this occasion. At top and bottom are the spectra of the primary beam, showing the $K\alpha$ doublet resolved and the $K\beta$ line just off the edge of the photograph. The second photograph

[4] For a more complete discussion of the theory, *cf.* A. H. Compton, *Phys. Rev.*, **21**, 483, 1923; P. Debye, *Phys. Zeitschr.*, Apr. 15, 1923.

shows the spectrum of the rays scattered by paraffin at 55° with the primary beam, and the third photograph that of the rays scattered at 90°. Within an experimental error which is very small indeed, the wave-length of the modified line shown in these photographs is the same as that of the primary, and the wave-length of the modified line is greater by the amount predicted by the quantum formula.

Clark and Duane, in certain recent spectroscopic measurements, using the K-rays from tungsten and a carbon radiator, have failed to detect a change in wave-length of this character.[5] Nevertheless, absorption and spectroscopic measurements, performed independently by Ross[6] and myself,[7] have shown such a change of wave-length occurring for the rays scattered by heavy as well as light elements, and for primary rays varying in quality from soft X-rays to hard gamma rays.

The simple theory as I have outlined it accounts only for the existence of the line whose wave-length is modified. It does not seem reasonable to suppose that this part of the radiation is scattered by quanta and the unmodified portion according to the classical theory. We can, however, account for the unmodified portion if we suppose that the incident quantum has an appreciable size, of the order of magnitude of a wave-length, and that if this quantum falls simultaneously on several electrons it will be scattered by the group. Thus a light wave falling on a silver mirror would be many times as long as the distance between two adjacent " free " electrons in the silver, and so would be reflected by a large group of electrons. But the total mass of the group would be so great that the energy lost in its recoil would be insignificant, and the corresponding change in wave-length would be negligible. This conclusion is in agreement with experiments published by Ross[8] and unpublished ones by Sir Ernest Rutherford. But if, as in the case of hard γ-rays, the wave-length is much less than the distance between the electrons in the scattering material, we should thus expect each quantum to be scattered by individual electrons and to give rise only to a ray of modified wave-length; a result also in accord with experiment. For intermediate radia-

[5] Clark and Duane, *Proc. Nat. Acad. Sci.*, Dec., 1923.
[6] P. A. Ross, *Phys. Rev.*, Nov., 1923.
[7] A. H. Compton, *Phys. Rev.*, Nov., 1923; *Phil. Mag.*, Nov., 1923.
[8] P. A. Ross, *Science*, 57, 614, 1923.

tions we should expect, on this view, that some of the quanta would fall on electrons relatively far removed from other electrons in the matter, which would scatter them as modified rays, and that other quanta would fall upon relatively compact groups of electrons which would scatter as units, giving rise to rays of unmodified wave-length. The problem of obtaining a quantitative criterion which will predict when modified scattering will occur, and when unmodified, is a most important one, for it is this criterion which determines whether or not interference is possible.

From the quantitative agreement between the experimental and the observed wave-lengths of the scattered rays, we may look with some confidence for the recoil electrons which result from the quantum theory of scattering. At the time that this theory was proposed there was no direct evidence for the existence of such electrons, though indirect evidence suggested that the secondary β-rays ejected from matter by hard γ-rays are mostly of this type. During the past summer, however, two experimenters, C. T. R. Wilson [9] at Cambridge, and W. Bothe [10] at Charlottenburg, have independently discovered by Wilson's cloud expansion method the existence of a new type of secondary β-rays which they have identified as these recoil electrons. Let me show you some of Wilson's photographs in which these new rays appear. Fig. 6 is a photograph obtained using X-rays that are not very hard. You will see four long tracks, originating in the path of the primary beam, which are produced by electrons which have absorbed the energy of a quantum of the incident rays and are ejected with a kinetic energy of about $h\nu$. These correspond to the photo-electrons. But there are also within the primary beam several very short tracks which appear as spheres. It is tracks of this character which Wilson has identified with the recoil electrons. When harder X-rays are employed, as in Fig. 7, these short tracks increase in length, and develop "tails" on the side of the incident X-rays. For this reason Wilson has dubbed them "fish" tracks. It is a significant characteristic of these fish tracks that their heads are all pointed in the direction of the incident X-ray beam, as is to be expected if they are due to recoil electrons. Let me show one more of Wilson's photographs, Fig. 8, showing both the long and the short tracks, which illus-

[9] C. T. R. Wilson, *Proc. Roy. Soc.*, **104**, 1, 1923.
[10] W. Bothe, *Zeitsch. f. Phys.*, **16**, 319, 1923.

FIG. 6.

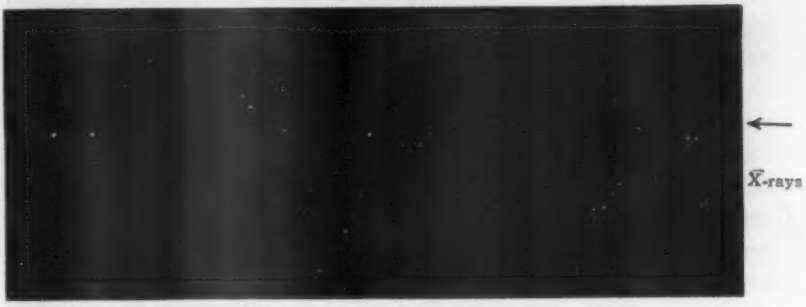


FIG. 7.

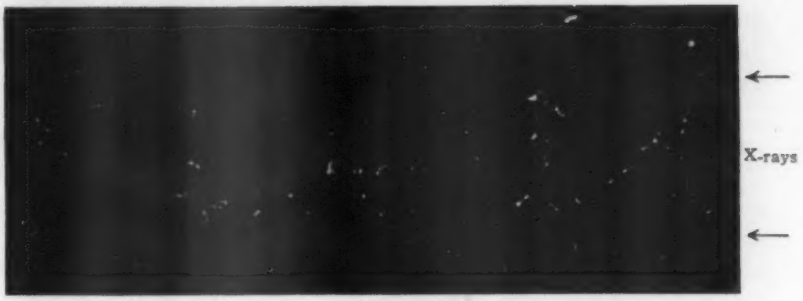


FIG. 8.

Cloud expansion photographs (Wilson) showing long β-ray tracks produced by photo-electrons and shorter tracks which are identified with the electrons recoiling from scattered X-rays.

trates the fact that the " fish " tracks which start directly forward are longer than those which move at an angle with the primary ray, corresponding to the difference in energy at different angles as predicted by our theoretical formula.

Wilson and Bothe both conclude that the direction and the range of these fish tracks is in agreement with the view that they are due to electrons which have recoiled from the quanta which they have scattered. Professor Hubbard and I have found also that the relative number of the long and the short tracks is in close agreement with what we should expect if each long track represents the fluorescent absorption of a quantum and each short track represents the scattering of a quantum of the incident X-rays. In view of the fact that these recoil electrons were unknown at the time this theory was presented, their existence and the close agreement with the predictions as to their number, direction and velocity supplies strong evidence in favor of the fundamental hypotheses of the quantum theory of scattering.

Regarding the intensity of the scattering of X-rays, I have already mentioned the fact that under certain favorable conditions Barkla and others have shown that the experiments are in good accord with Thomson's classical theory. But the experiments show conclusively, I believe, Professor Barkla to the contrary [11] notwithstanding, that when X-rays of short wave-length are employed the intensity falls distinctly below the minimum value predicted on the usual electrical theory. A number of unsuccessful attempts have been made to modify the electron theory in such a manner as to account for the low intensity and the unsymmetrical distribution of the scattered rays when hard X-rays and γ-rays are employed. These attempts have only served to emphasize that a very radical departure, indeed, is required to account for these phenomena.

It has not been found difficult, however, to account for this dissymmetry and feeble scattering on the basis of the quantum postulate. Both Professor Jauncey [12] and I [13] have obtained, by widely different though somewhat arbitrary methods, formulas for the intensity of X-ray scattering from the quantum standpoint. The resulting formulas, which are nearly identical,

[11] C. G. Barkla, *Nature*, Nov. 17, 1923.
[12] C. E. M. Jauncey, *Phys. Rev.*, **22**, 233, 1923.
[13] A. H. Compton, *Phys. Rev.*, **21**, 491, 1923.

approach Thomson's theoretical expression for great wave-lengths; but for shorter wave-lengths they indicate a reduced and unsymmetrical scattering. In this region where the classical formulas fail, the quantum expressions are found to fit the data probably within experimental error. In view of the fact that no new constants are introduced to secure this result, this agreement gives strong support to the quantum scattering postulates.

I have already remarked that experiments to detect the shift in wave-length when light is scattered or reflected have given negative results. This is in line with the fact that for X-rays of great wave-length part of the scattered ray is of the unmodified kind. This has been explained as due to scattering by groups of electrons if the wave-length is much greater than the distance between the adjacent electrons. In one interesting case, however, the scattering electrons are far apart even as compared with the wave-length of light. I refer to the electron atmosphere of the sun, which is present due to the dissociation by heat of the gases in the photosphere. Here we might look for a change of wave-length for the scattered rays, which should be greater near the sun's limb, where the light rays reach us after traversing a thicker layer of free electrons. A difference in wave-length of spectrum lines from the edge and from the centre of the sun, known as the "limb" effect, of origin unknown, has been recognized by solar spectroscopists for many years. Its sign is right and its magnitude is of the proper order to be accounted for as being due to the same process of quantum scattering as occurs with X-rays.

In a recent number of the *Zeitschrift für Physik*, Pauli [14] has considered the interaction of radiation and electrons in a reflecting enclosure, and has found by a thermodynamical argument that if the wave-length of the rays is altered by scattering, the energy absorbed by an electronic oscillator in a field of radiation depends not only upon the radiation reaching the electron, but also upon the radiation which the electron is about to emit. In other words, the action of the electron is conditioned not only by present and past events, but also by events which have not yet happened.

Unquestionably the most important result of this work, however, is the information which it gives regarding the nature of

[14] Pauli, *Zeitsch. f. Phys.*, **18**, 272, 1923.

electromagnetic radiation. We find that the wave-length and the intensity of the scattered rays are what they should be if a quantum of radiation bounced from an electron, just as one billiard ball bounces from another. Not only this, but we actually observe the recoiling billiard ball, or electron, from which the quantum has bounced, and we find that it moves with just the speed it should if a quantum had bumped into it. The obvious conclusion would be that X-rays, and so also light, consist of discrete units, proceeding in definite directions, each unit possessing the energy $h\nu$ and the corresponding momentum h/λ. So in a recent letter to me Sommerfeld has expressed the opinion that this discovery of the change of wave-length of radiation, due to scattering, sounds the death knell of the wave theory of radiation.

If we wish to avoid this conclusion and to retain the idea that energy proceeds in all directions from a radiating electron, we are presented with an alternative which is perhaps even more radical, namely, that when dealing with interactions between radiation and electrons, the principles of the conservation of energy and of momentum must be abandoned. It is indeed difficult to see how the idea of directed quanta can be reconciled with those experiments in which interference is secured between rays that have moved in different directions, as for example in the interferometer. The conviction of the truth of the spherical wave hypothesis produced by such interference experiments has led Darwin and Bohr in conversation with me to choose rather the abandonment of the conservation principles.

The manner in which this alternative presents itself is very clear-cut. If the energy radiated by an electron striking the target of an X-ray tube is distributed in all directions, only a very small fraction of it will fall upon any particular electron in the scattering material. But this small fraction of the original radiated energy is sufficient to enable the scattering electron to emit a whole quantum of radiant energy. That this is true is shown by the fact that the number of recoiling electrons observed in the Wilson photographs is no larger than the number of scattered quanta, while the change in wave-length of the scattered rays shows that they have all come from these rapidly moving electrons. Thus on the spherical wave hypothesis, when a scattering electron radiates, it emits many times as much energy as it receives from

the incident radiation. In the corresponding case of the photo-electric effect, we sometimes try to explain this difficulty on the view that energy is temporarily stored up by the electron. In the present case, this view is even more difficult to defend than in the case of the photo-electric effect, for here the loosely bound electrons, and apparently even the free electrons as well, would have to be able to store up energy as readily as those tightly bound within the atom.

The lack of conservation of momentum on the spherical wave view is even more clearly evident than is the sudden appearance of energy. For just as in the case of the energy received by the scattering electron, so also the impulse received by the electron from the incident radiation is on this view insignificant. We find, however, that the scattering electrons move with a velocity comparable with that of light, an electron suddenly acquiring a momentum in the forward direction which is incomparably greater than the impulse which it receives from the incident ray on the usual wave theory. To retain the conservation of momentum, we might suppose that the remaining part of the atom recoils with a momentum equal and opposite to that of the scattering electron. But the experiments indicate that the momentum may be equally well acquired whether the electron is loosely or tightly bound, and there is even evidence that the free electrons in an ionized gas acquire momentum in the same manner. It is thus clear that the momentum acquired depends only upon the scattering electron and the radiation, and has nothing to do with the remaining part of the atom. If, therefore, as the spherical wave hypothesis requires, radiation does not impart to the electron an impulse as great as it is found to acquire, the momentum is not conserved in the process, that is, action and reaction are no longer equal and opposite.

If this work on the scattering of X-rays is correct, we must therefore choose between the familiar hypothesis that electromagnetic radiation consists of spreading waves, on the one hand, and the principles of the conservation of energy and momentum on the other. We cannot retain both.

It seems to me that the very fact that the energy and momentum principles may be applied to the problem of the scattering of radiation with results in accord with experiment, constitutes

a test of their validity for phenomena of this type. For this reason I am inclined toward the choice of these principles even at the great cost of losing the spreading wave theory of radiation. I am by this choice confined to the view that radiation consists of directed quanta. Following perhaps the trail blazed by Duane [15] for interference of plane waves, I still have hope that a path may be found for the quantum theory to pass also through the difficulties presented by other interference experiments.

A New Measurement of the Pressure of Radiation. ALICE GOLSEN. (*Ann. der Physik*, Vol. 73, Nos. 7 and 8.)—When Ehrlich, in 1918, published his observations on particles that travel up the stream of radiation toward its source he led to renewed investigations of the actions of radiometer vanes placed in vacua of different tenuity. It was found that there were still radiometric effects at the pressure of gas under which Lebedew made his classic measurements of radiation pressure at the beginning of this century. In the present experiment examination showed that, at a pressure of 10^{-5} mm. Hg, the medium ceased to have influence on the mechanical effects produced by a beam of radiation. In a vacuum of this order of pressure a vertical quartz fibre supported a horizontal arm carrying at one end a piece of metal foil in a vertical plane and at the other end a counterweight. A beam from a tungsten arc lamp impinged on the foil and pushed it around until the twist of the fibre and the force exerted by the beam were in equilibrium. The deflection thus called forth was of unusual constancy. Of course it depended on the metal of which the foil was made. Aluminum had a reflecting power of 81 per cent., nickel 43 per cent. and platinum 60 per cent. Theoretically the pressure in dynes on one square centimetre of the foil due to the radiation should equal numerically the ergs of energy in one cubic centimetre of the beam near the foil. The smaller the amount of radiation reflected, the less the energy in the unit volume of the beam and consequently the smaller the pressure exerted on the foil. The actual mechanical force on the foil was calculated from a knowledge of the constants of the quartz fibre, of the arm and the deflection. The energy in unit volume was obtained from a study of the energy flux from the lamp. A comparison of these two quantities thus computed showed that they were in agreement to within a few per cent. The average difference was about 3 per cent., provided we disregard the fact that in part of the cases one quantity was the larger and in other instances the second quantity exceeded the first, that is, that the differences are partly positive and partly negative. G. F. S.

[15] W. Duane, *Proc. Nat. Acad. Sci.*, Apr., 1923; A. H. Compton, *Proc. Nat. Acad. Sci.*, Nov., 1923.

ACOUSTICS OF AUDITORIUMS.*

BY

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THE knowledge of the acoustical properties of rooms has advanced very materially in recent years, due largely to the pioneer investigations of the late Prof. Wallace C. Sabine. A number of publications are now available that describe the action of sound in rooms and that illustrate many phases of the subject. In two important practical considerations, however, the writer has found but little information, namely, concerning the loudness of sound and the time of reverberation that are acceptable to auditors in auditoriums of different volumes. The present article is intended to set forth a discussion of these factors.

For satisfactory hearing an average sound should rise to a suitable intensity in every part of the auditorium, with no echoes or distortion of the original sound, and should then die out quickly enough to leave the field free for the succeeding sound. These ideal conditions are rarely found, but, fortunately, a moderate departure from the ideal is not greatly objectionable so that any auditorium of usual size and shape may be designed to have acceptable acoustics.

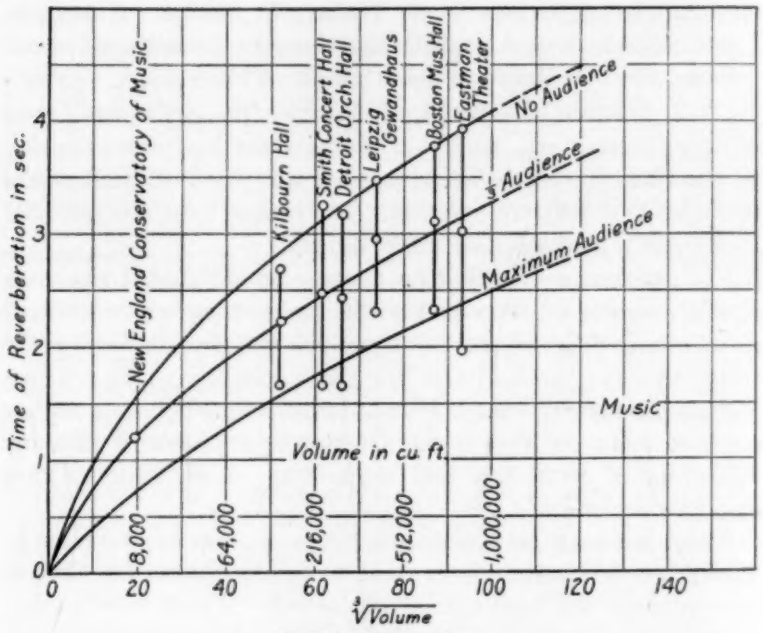
From the practical standpoint, the most important factor in securing good acoustics is the time of reverberation, but this, in turn, involves the loudness of the sound. These two factors, an acceptable loudness and suitable time of reverberation, are obtained, first of all, from the opinions of auditors. To secure this information, reliable opinions should be obtained on the acoustic properties of a considerable number of auditoriums that vary in shape and size. After this has been done, the scientist, by means of quantitative measurements, can formulate general equations that include the data secured and that allow definite estimations to be made for new auditoriums. It should be noted that these requirements are not independent of each other because

* Communicated by the Author.

the sound-absorbing material introduced into rooms to reduce the time of reverberation acts at the same time to reduce the loudness of the sound. A compromise must then be made to secure the best solution.

The mathematical equations for loudness and time of reverberation are known, but published accounts that coördinate theory and practice are quite meagre, so that the relations proposed for

FIG. 1.



Acoustics of auditoriums.

guidance at the present time may be regarded as pioneer efforts that point the way to the final solution. The writer in his book on "Acoustics of Auditoriums" proposed two such general relations for loudness and time of reverberation that have served for guidance in the acoustic design of new auditoriums, or in the correction of those with faulty acoustics. The discussion of the relations in the book mentioned was purposely minimized to accord with the plan of the text, so that a more extended explanation of the subject appears desirable.

For definiteness of discussion, the first relation in question is quoted.[1]

"*Acceptable Time of Reverberation for Auditoriums of Different Volumes.*—An important factor, and one that must be known when correcting or designing the acoustics of an auditorium, is the time of reverberation that will give the best results. This information is obtained by tabulating the acoustic data of auditoriums that are pronounced good by public opinion. The results of such a study, for concert halls, are shown in Fig. 1. The data are presented in the form of curves, where for different auditoriums, the time of reverberation is plotted for no audience present in the hall, for one-third audience and for the maximum audience. The time of reverberation is assumed to vary with the cube root of the volume of the auditorium. This relation may be deduced from theory, assuming that the average absorption per unit area is the same for all auditoriums. It is to be noted that the time increases with the size of the auditorium, so that a large auditorium requires a greater time than a small one."

The formula is derived as follows. Consider Sabine's equation:

$$t = .05V \div as,$$

where t is the time taken for a sound of average intensity to die out, V is the volume of a room in cubic feet, and as is the total absorption of all the surfaces in the room. Now

$$as = a_1s_1 + a_2s_2 + a_3s_3 + \ldots$$

where the surfaces s_1, s_2, s_3, . . . and the absorbing coefficients a_1, a_2, a_3, . . . refer to the different surfaces and materials in the room, and a is the average coefficient of all the materials and s the total surface.

For simplicity, apply the formula to a spherical auditorium of radius r, for which

$$V = 4/3\,(\pi r^3), \text{ and } s = 4\pi r^2,$$

then

$$t = \frac{.05V}{as} = \frac{.05\ 4/3\ (\pi r^3)}{a\ 4\pi r^2} = \frac{.05r}{3a}, \text{ or } t \propto \frac{r}{a}.$$

Since r is fixed by the volume of the room, it is seen that any

[1] "Acoustics of Auditoriums," p. 30.

adjustment of the time t depends on a, the average absorption of sound per unit area. Experience in securing satisfactory acoustics shows that the total absorption should increase with the size of the auditorium, and the usual practice in securing good acoustics in large auditoriums is to provide additional absorbing material in the shape of hairfelt, carpets, curtains, upholstered seats, etc. The question to be decided is how much the absorption shall increase. Two limiting cases suggest themselves and these are the ones discussed in this paper, namely, where a is constant and where a increases in proportion to r. If a is constant, it does not mean that the total absorption is the same for all auditoriums, but that it increases in such amount that the total absorption divided by the total surface area shall have the same value for all auditoriums.

Mathematically, if a is assumed constant, we have the relation:

$$t = \frac{.05r}{3a} = \frac{.05\sqrt[3]{4/3\,\pi r^3}}{3a\sqrt[3]{4/3\,\pi}} = \text{constant} \times \sqrt{\text{volume}}$$

or, in words, the time of reverberation varies with the cube root of the volume. Auditoriums met with in practice are not spherical nor any other particular geometric form, but the cube root of the volume is an ideal dimension that serves acceptably in practice when comparing different auditoriums, whatever their shapes may be. By means of this relation, values of t and $\sqrt[3]{\text{volume}}$ were plotted for a number of auditoriums, whose acoustic properties are already known, as shown in Fig. 1; thus furnishing satisfactory guidance for use in the design of new auditoriums.

On the other hand, consider that $a \propto r$, which leads to the result that the time of reverberation is constant for all auditoriums. Since r is proportional to the cube root of the volume, the average absorption per unit area a increases as the cube root of the volume. For practical illustration, consider two rooms investigated by the writer: The Eastman Theatre in Rochester, New York, and a small music studio at the University of Illinois. If this relation is correct that the time of reverberation is constant, each square foot of the surface in the Eastman Theatre would have to absorb on the average 6.2 times as much sound as each square foot of surface in the small music studio; that is, in the ratio of the cube roots of the volumes, $\sqrt[3]{790{,}000}$ to $\sqrt[3]{3360}$, or

6.2. To accomplish this result, a considerable amount of absorbing material would have to be added to the Eastman Theatre, which is already regarded as satisfactory.

Further information regarding the best amount of material to install is found in the published works of Professor Sabine. Professor Sabine describes in detail two cases involving the time of reverberation. One is the Boston Music Hall,[2] a large auditorium with a volume of 649,000 cubic feet, for which after a careful study, Professor Sabine prescribed the value of 2.31 seconds as the acceptable time of reverberation and obtained results that were considered satisfactory. The other case involves a number of small music studios in the New England Conservatory of Music,[3] the volumes varying from 74 to 210 cubic metres (4270 cubic feet for the average of five rooms). A number of musical experts listened in each of these rooms to piano music as increasing amounts of absorbing material were introduced and expressed opinions concerning the acceptable condition for best effect. On the basis of these opinions, Professor Sabine conducted subsequent experiments and calculated the average time of reverberation to be 1.08 seconds as the suitable time for rooms of this size.

These values, which are the only numerical ones the writer recalls reading in Professor Sabine's works, would certainly lead to the conclusion that the time of reverberation should increase with the volume of the auditorium. Consider what the result would be if a single value were used for the two cases described. The logical time to select as the ideal would be 1.08 seconds, since this value was determined under experimental circumstances that left no doubt of its correctness. To reduce the time of reverberation in the Boston Music Hall to the value of 1.08 seconds, it would be necessary to install approximately 29,000 square feet of hairfelt one inch thick, which would greatly deaden the Hall from its present state which is considered satisfactory.

If other auditoriums are considered, the same conclusion is reached. The writer tested two small music studios at the University of Illinois, each with a volume of 3360 cubic feet.[4] From the opinions given by expert musicians, the time of reverberation for satisfactory acoustics was calculated to be one second. In

[2] "Collected Works," p. 67.
[3] *Loc. cit.*, p. 75.
[4] "Acoustics of Buildings," p. 51.

comparison with these studios, consider the Eastman Theatre with a volume of 790,000 cubic feet, for which, according to the curve given in Fig. 1, a time of reverberation of 2.08 seconds was prescribed for the case when a maximum audience was present. The outcome justified the estimation, for the authorities of the Eastman Theatre regard the acoustics perfect. If for these two cases, a single time of reverberation were used, the smaller value would be the more accurate because determined under controlled experimental conditions. Applying this time of one second to the Eastman Theatre would mean the additional installation of approximately 37,000 square feet of one-inch hairfelt—enough to cover the entire ceiling and a considerable area of the side walls. The addition of this large amount of absorbing material to the theatre, which is considered perfect with its present furnishings, would certainly make it too dead acoustically.

It would thus appear better to have the time of reverberation increase with the volume of an auditorium, rather than remain constant; that is, it accords more closely with satisfactory conditions to keep a, the average absorbing power per unit area, constant than to have it increase with the volume.

If now, the second factor for satisfactory acoustics—the loudness—be considered, the whole problem receives additional light in its solution.

For an auditor to hear comfortably, the sound affecting his ears should produce an acceptable sensation of loudness. This means, in an auditorium, that each unit of volume on the average must contain a suitable amount of sound energy and this must be the same whether the auditorium is large or small. The amount of energy need not be a single definite value, but may vary over a considerable range, provided the resulting sound is neither too loud nor too faint. Some intermediate value will probably give an ideal effect. Expressing this mathematically, the intensity per unit volume, E_o,[5] must be constant for all auditoriums, or

$$E_o = 4A \div vas = \text{constant},$$

where A is the energy given out per second by the vibrating body—musical instrument, voice—v is the velocity of sound, and as has the same value as given earlier in the discussion.

From this equation it is seen, if the ideal condition of average

[5] "Acoustics of Buildings," p. 27.

loudness is obtained, that A, the source of sound, should increase its energy in proportion to the product as. Since the surface s is fixed by the dimensions of the room, the value decided on for A depends finally on the factor a, the average absorbing power per unit area of all the surfaces in the room. Should this factor increase, remain constant, or decrease as the volume increases? The answer to this question is not answered solely by considering the source of sound A and the resulting intensity E_o, but by regarding also the time of reverberation which is fixed by the value of a. A compromise must be made that gives the best solution for both the intensity and time of reverberation. A definite step toward the solution is taken by considering the two values of a discussed already in connection with the time of reverberation, namely, first, where a is constant, and second, where a increases in proportion to the cube root of the volume of the auditorium.

If a is assumed constant,

$$E_o = \text{constant} = CA \div s$$

where C is a constant. It then follows that A, the generator of sound, should increase its output of energy in larger auditoriums in proportion to s, the total area of the bounding surfaces of the auditorium, or since, for a spherical auditorium, $s = 4\pi r^2$, and $r \propto \sqrt[3]{\text{volume}}$, that $A \propto (\sqrt[3]{\text{volume}})^2$. It is quite obvious that in large auditoriums the energy of the sound source should be greater than in small auditoriums; for instance, a weak-voiced speaker can be heard acceptably in a small room, but a large auditorium requires a speaker with a vigorous voice. This relation, just developed, that the energy of the sound increases with the total area of the room, accords quite acceptably with the acoustic conditions existing in a number of auditoriums, as explained in Fig. 14 in the book on "Acoustics of Buildings."

Suppose now, instead of regarding a as a constant, that a value be taken to conform with the assumption that the time of reverberation is constant, namely, that $a \propto r \propto \sqrt[3]{\text{volume}}$, as already explained. Since $E_o = \text{constant}$, and $s = 4\pi r^2$, it follows that $A \propto as \propto r^3 \propto \text{volume}$, or, in words, A, the energy of the source of sound, should increase in direct proportion to the volume of the auditorium. For illustration, if one piano gives acceptable results in the studio of 3360 cubic feet volume, the Eastman Theatre with a volume of 790,000 cubic feet would require 790,000 ÷ 3360,

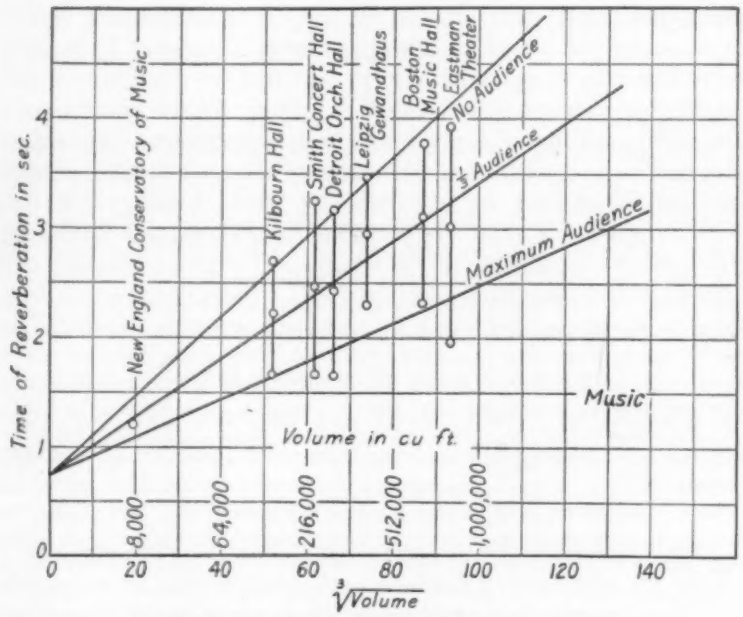
or 263 pianos, to give the same acceptable effect. According to the relation proposed by the writer, thirty-eight pianos $[(790{,}000)^{3/2} \div (3360)^{3/2} = 38]$ would be needed in the Eastman Theatre—a result that seems more reasonable. Or again, a speaker who can be heard with satisfaction in an auditorium of 50,000 cubic feet would be obliged to increase the intensity of his voice sixteen times, if $a \propto \sqrt[3]{\text{volume}}$, to give the same results in a hall of 800,000 cubic feet, but only 6.4 times according to the relation proposed by the writer.

Here again, as in the case of the time of reverberation, it appears better to keep a, the average absorption per unit area, constant for auditoriums of different volume than to increase it in large auditoriums. This conclusion leads to the relations that the acceptable time of reverberation varies with the cube root of the volume of an auditorium and that the energy of the source of sound increases in proportion to the area of the surfaces. Both of these relations were proposed by the writer in his book on "Acoustics of Buildings." It should be noted that if a, the average absorption per unit area, is kept constant for all auditoriums, it does not mean that the total amount of sound-absorbing material is the same for all auditoriums, but that absorbent must be added in the larger rooms to make each unit area of surface on the average have the same absorbing power as an equal area in the smaller rooms. The absorbing material need not be spread uniformly over the surface of the room, but may be concentrated in certain areas, such as a carpet on the floor, hairfelt on the ceiling, etc. The value of a is obtained by dividing the total amount of absorption for the whole room by the total surfaces of the room.

Several other considerations remain to be discussed. It has been shown that ideal acoustic conditions prevail in an auditorium when the sound produces the most comfortable sensation of loudness and then dies out in a suitably short time. Both of these qualities depend on the absorbing material in the room which serves to reduce the time of reverberation to the acceptable value and also to deaden the intensity to give the proper loudness. Passing now to a larger auditorium, more absorbing material must be used to give the acceptable time of reverberation, but if we have the same source of sound, say a speaker, the additional absorbing material reduces the intensity of the sound of his voice

and the loudness falls below the ideal. If, on the other hand, we pass to a smaller auditorium with a smaller amount of absorbing material, the sound becomes louder. We thus come to the conclusion that, for an average speaker, there is only one size of auditorium that possesses ideal acoustic conditions.[6] Fortunately, a departure from the ideal is not greatly objectionable. The time of reverberation may vary about 5 per cent. without noticeable effect. The intensity of the sound, which determines

FIG. 2.



Modified curves giving time of reverberation for auditorium.

the loudness, may change more markedly than the time of reverberation. It appears that the ear is quite insensitive to changes in intensity, a fact which is understood when we remember that we can hear a softly played violin and also an orchestra in the same auditorium. The time of reverberation depends on the intensity of the sound in about the same way as loudness does, that is, a large change in the intensity is required to make a small

[6] This objection may be minimized in large auditoriums by the use of modern electric devices that serve to amplify the sounds of the speaker's voice.

change in the time. Mathematically, the time of reverberation and the sensation of hearing are proportional to the logarithm of the intensity. From this reasoning we conclude that the time of reverberation is a more important factor than the intensity in determining the conditions for acceptable acoustics in a room.

The curves shown in Fig. 1 furnish a definite guidance in selecting the acceptable time of reverberation for auditoriums of different volume. While giving satisfactory results for large auditoriums, these curves indicate for rooms with small volumes that the time of reverberation should have a small value, which means that these rooms should be very dead acoustically with a large amount of sound-absorbing material installed. Experience shows that this is not satisfactory, that such rooms are not comfortable for auditors and that they should have some reverberation with only a moderate amount of sound absorbent. Therefore, the curves are modified as shown in Fig. 2, in which straight lines are substituted for the curves. These lines give a time of reverberation of about 0.75 second for the smallest rooms and other times in proportion to the volume. For an auditorium with no audience present the acceptable time of reverberation would be given by the upper straight line, or by the formula

$$t = t_0 + k\sqrt[3]{\text{volume}} = 0.75 + 0.375\sqrt[3]{\text{volume.}}$$

For example, an auditorium of 512,000 cubic feet, for which $\sqrt[3]{512{,}000} = 80$, should have a time of reverberation for no audience present of

$$t = 0.75 + 0.0375 \times 80 = 3.75 \text{ seconds.}$$

In conclusion, if the discussion of the paper is summarized, it appears for satisfactory loudness and reverberation in an auditorium, that absorbing material should be increased with the volume of the room. To fulfil these conditions, the writer proposes that the absorbent be installed in such amounts that the average absorption per unit area remain constant. This procedure leads to two relations that accord closely with the conditions found in satisfactory auditoriums, namely, first, that the acceptable time of reverberation should vary with the cube root of the volume and, second, that the source of sound should increase in energy output in proportion to the total area of the surfaces in the room.

To definitely settle the question of the best amount of material to install in rooms to obtain the best acoustic conditions, it appears

desirable to conduct experiments to secure opinions simultaneously on the loudness and the time of reverberation for a considerable number of different auditoriums and sources of sound. At the same time, quantitative experiments, with instruments if possible, should be conducted in order that numerical constants may be determined.

In the meantime, largely in response to many inquiries from architects and builders for guidance, the writer formulated the two practical rules that include data of known auditoriums and used these with success in prescribing conditions for a number of new auditoriums. These rules appear acceptable for guidance until more definite information is available.

On the Critical Frequency of Pulsation of Tones. On the Effect of Aural Fatigue upon the Critical Frequency of Pulsation of Tones. MOLLIE WEINBERG and FRANK ALLEN. (*Phil. Mag.*, Jan., 1924, pp. 50 and 126.)—A tonvariator was blown within a box lined with felt. The tone produced escaped through a hole in the side of the box, in front of which rotated an aluminum disc having four holes of the same size as that in the box. "In making the measurements the tonvariator was adjusted to give a steady sound of the desired pitch and intensity. The ear was then placed at the proper place and the speed of the disc increased so that the interrupted pulses of sound became fused into a just continuous sensation. The chronograph circuits were then closed and the readings recorded. For each pressure or intensity of sound such measurements were made for seven frequencies extending through the octave." In presenting the results the "duration of the tone at the critical frequency of pulsation," the blowing air pressure and the vibration frequency of the tone are connected. For all pressures the duration grows less as the pitch of the tone rises. The relation is almost linear. The lower the pressure the lower is the duration for a given pitch.

In studying the effects of fatigue the ear was subjected to the sound of a second tonvariator for two minutes. After exposure for this time it seemed that no further fatigue was produced by continuing the process. The "duration" was then determined over a range of vibration frequencies 15 above and 15 below the fatiguing tone. "The curves indicate that as a result of fatigue the persistency of sound impressions is greatly increased. This increase is a maximum when the frequency of the fatiguing tone is the same as that upon which measurements are taken, and diminishes very rapidly as the interval from the fatiguing tone is increased. The entire range affected is about sixteen vibrations, or about eight on each side of the maximum."

G. F. S.

Electric Light and Sunlight for Plants. (*Clip Sheet No. 312*, U. S. Department of Agriculture.)—The discovery that the seasonal blossoming and fruiting of plants is caused by the length of day, made a few years ago by investigators in the United States Department of Agriculture, has been completely confirmed by experiments with artificial light and colored light. Previous to these investigations, which were carried on by W. W. Garner, H. A. Allard, and R. A. Steinberg, of the Bureau of Plant Industry, normal plants never had been fully developed under artificial light, but it has been shown that under such conditions plants can be grown normally and will produce normal seed.

Artificial control of all the conditions necessary to the normal development of the plants from germination to maturing of the seed has been secured by specially designed apparatus to which no daylight can enter. The light rays from a gas-filled tungsten lamp are filtered through a layer of running water which carries away most of the heat while interfering very little with the passage of the light. By means of colored glass or colored chemicals in the water, sunlight can be simulated or light of widely different colors or spectral composition can be obtained, as well as lights of intensities equal to or greater than that of sunlight. The day length is regulated by electric time switches which turn the lights on and off at the desired time. Inside this apparatus daily and seasonal changes may be made to go on at complete variance to the days and seasons going on outside.

Among the more than sixty species of plants which have been grown under these conditions are lettuce, celery, spinach, morning glory, Rudbeckia, Godetia, cypress vine, soybean, bidens, chenopodium, and poinsettia.

With all these plants the response to the length of day has been the same as in sunlight. The "short-day" plants, the characteristic autumn and winter blossoming plants, blossom when exposed to the short artificial day. The summer blooming plants blossom when given a long day under electric lights.

Practical conditions, say the investigators, preclude the use of artificial light in place of daylight, but it will be possible in growing some greenhouse plants to extend the natural day by use of electric lights to speed up blooming. Obviously this practice will be useful in case of "long day" and "indeterminate day" plants. A relatively low-power illumination can be used, extending the length of day from sixteen to eighteen hours for many plants. Intense lights have been found unnecessary and wasteful. It is said that for commercial use engineers and greenhouse men must work out the particular requirements of special crops.

Experiments have shown the fallacy of a rather widely accepted view of plant physiologists, particularly those in Europe, that certain wave-lengths of visible light are essential to normal development of green plants. Healthy normal seed has been produced with wide variations in composition of the light used.

TURBINE DRIVE FOR PROPELLER MODELS.*

BY

L. H. CROOK.

Bureau of Construction and Repair, U.S.N.

FOR the study of forces on an airplane model in a wind-tunnel, one frequently needs a mechanism to drive, at very high rotational speed, a model screw propeller held at various angles and positions before the airplane model. The speed of the wind may be thirty or more miles an hour. The rotational speed of the screw must then be such as to make the angle of attack of the blade against the onrushing air substantially the same as in full-scale flight. The little screw may therefore have to make 20,000 turns a minute, without excessive noise, heating or shaking, and with sufficient constancy for accurate measurements both of its own speed and of the air forces acting on the model held in its wake. The drive connections must disturb the general air-flow as slightly as possible, yet transmit to the air-screw two to three horsepower. In the present case the sole function of the power system was to throw upon the airplane model a stream geometrically similar to that experienced by the full-scale airplane in usual or contemplated flight conditions. The motor was not required to ride within the model, as in certain well-known electric drive systems.

Previous experimenters had mounted the propeller on a shaft in bearings which were held nearly coaxial with the air-stream by fine wires anchored to the tunnel corners. A small pulley on the shaft was turned with a wire belt from a motor outside the tunnel. In a different device the shaft, having no pulley, was driven by its end with a flexible wire from a high-geared electric motor outside. In a third arrangement the flexible wire, thus attached to the shaft, was actuated by an air turbine outside. This latter scheme was reported unsatisfactory because of the shrill howling of the engine, the trembling of the wire, and the heating of it in its bearings.

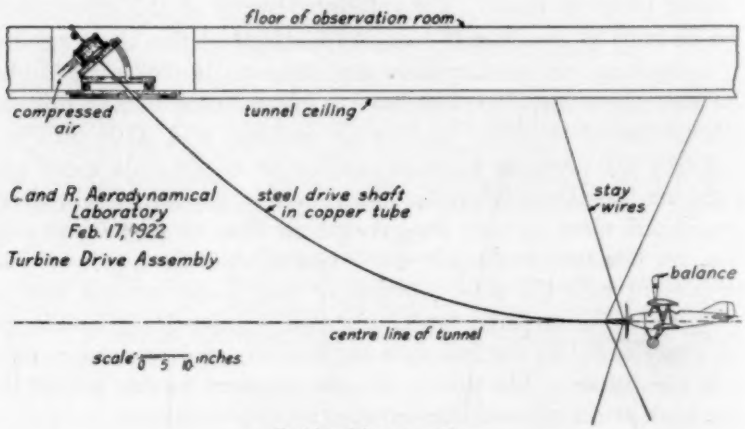
The latter type seemed most convenient for the Aerodynamic Laboratory of the U. S. Navy, where compressed air, at about

* Communicated by A. F. Zahm, Associate Editor of this JOURNAL. Report of work done for Bureau of Aeronautics, U. S. N.

ninety pounds per square inch, is always available. Such an instrument was therefore designed for the Bureau of Aeronautics, U. S. N., by the present writer, constructed in the shops of the Washington Navy Yard, and satisfactorily employed in the 8 by 8 foot wind-tunnel in August, 1922. It answered all the requirements above specified.

Fig. 1 delineates the general drive assembly in its working environment. From the air turbine above the tunnel a 3/16-inch drive wire, encased in an easy fitting copper guide tube, runs

Fig. 1.



Turbine drive assembly.

obliquely through the ceiling, thence curves down stream to the propeller, which is supported before the airplane with fine wires stretched across the tunnel. The airplane model is independently supported on the holder of the aerodynamic balance, which holder runs up vertically through a wind-shield to the force and moment balance in the room overhead. The observer at the balance, by working the rheostat that governs the tunnel fan, can hold the wind steady at any speed up to seventy miles an hour.[1] The observer at the turbine controls its speed with the compressed-air inlet valve, and reads the speed with a tachometer or speed meter joined to the outer end of the engine shaft. The overall dimen-

[1] Uniform winds of any fixed speed, from 30 to 150 miles an hour, can be had when, with movable liners, the 8 ft. by 8 ft. tunnel section is reduced to 4 ft. by 4 ft.

sions may be inferred from the appended scale in Fig. 1. A closer view of the screw, with another type of airplane, is given in Fig. 5.

As seen in Fig. 2, the turbine engine is mounted on an

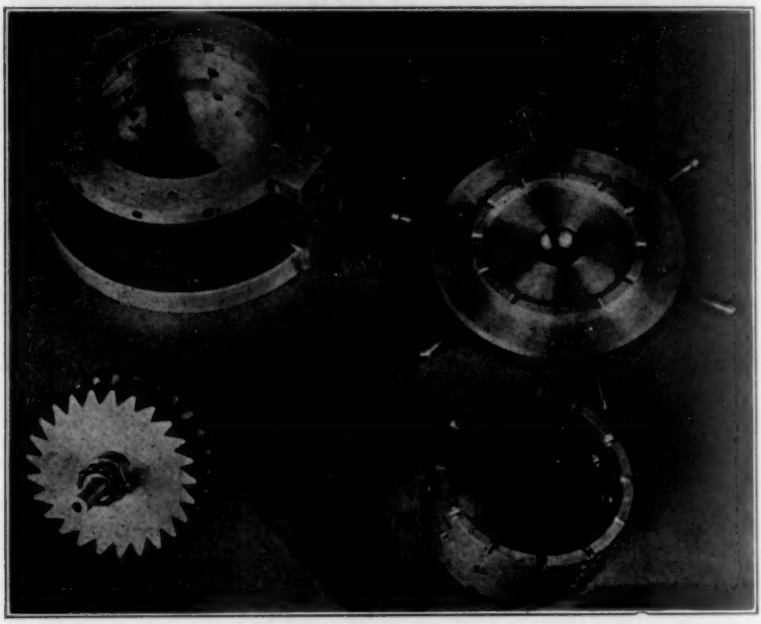
FIG. 2.

Turbine at work.

inclinable base, which is supported at a convenient height by a machinist's clamp-stand bolted on top of the wind-tunnel. Below this wooden base one sees the copper tube, which encases the drive wire, running obliquely through a slot in the lid of the tunnel

ceiling. At the top end of the turbine shaft a speed counter is held in a sheet metal bracket clamped by two screws to the cylinder head. Two compressed-air feed pipes, each having its own hand valve, supply two toothed wheels mounted on the turbine shaft within the same cylinder. When full power is needed both valves are opened. Usually but one is opened, and that not entirely.

Fig. 3.



Turbine disassembled.

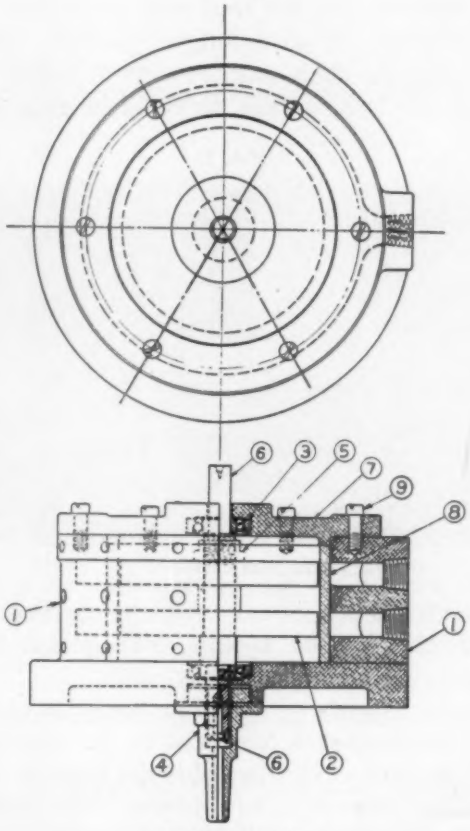
Three rows of exhaust holes are seen. The middle row is between the two wheels; the others beyond them.

Inside the engine case, which is an aluminum casting, is a close-fitted lining which forms the turbine cylinder, as seen disassembled in Fig. 3. Around this lining, but cut in the outer casing, are two annular grooves large enough to convey the feed air slowly about the cylinder. From each annular groove the air rushes into the cylinder through four holes, drilled obliquely as shown, and strikes tangentially against the spinning rotor. Each jet on striking a turbine blade divides symmetrically and emerges

through the exhaust ports drilled radially through the cylinder and its close-fitting aluminum case.

The chief dimensions and other details are given in the scale drawing (Fig. 4). The turbine wheels, four inches in diameter, are milled from steel discs one-half inch thick. Each has twenty-

FIG. 4.



Turbine assembly.

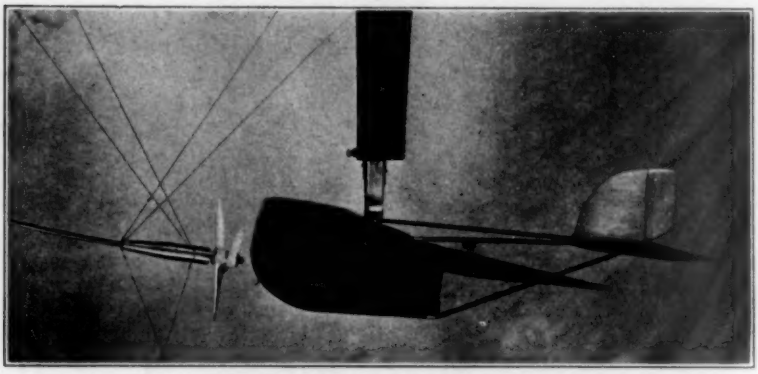
five blades, of slightly concave face and of moderate clearance. The steel shaft runs in ball-bearings contained in the casing hubs, top and bottom. Though the casting is of aluminum, the sleeve was made of a drawn pipe which happened to be of bronze.

The transmission line, twelve feet long, is a 3/16-inch spring steel wire rotating inside a one-quarter-inch copper tube, which

serves as guide and bearing surface. The tube, when fixed at its ends to the bearing of the engine and propeller, required no stays to steady it in the wind, and was not materially shaken or heated by the shaft at its highest speed.

To obviate heating, due to surface friction and internal viscosity, the shaft had been made quite straight and hard by stretching it vertically, raising it to red heat with an electric current, and allowing it to temper by air-cooling in position. When, during a preliminary test, the shaft was run without temper, it developed excessive heat due to hysteresis, as could be expected from 300

FIG. 5.



Airplane and screw.

large stress reversals per second. After tempering, it ran indefinitely without objectionable heating, even in still air, when the pipe was well curved and moderately oiled.

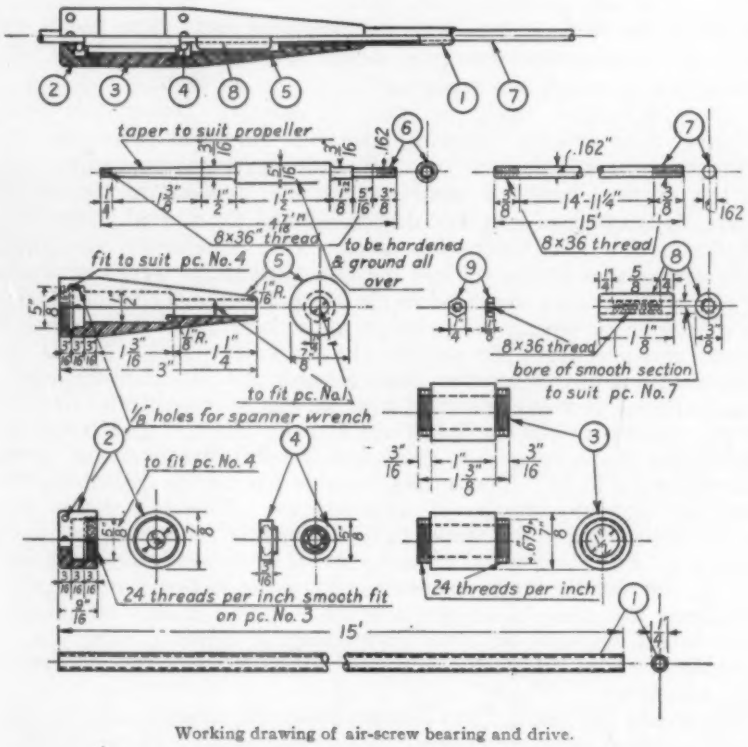
The external support of the propeller housing and airplane model, at any angle to each other and to the wind, is effected as shown in Fig. 5. Six wires attached to the housing, and tensioned with turn buckles, moor it in mid-stream. The airplane model is mounted on the wind-balance shank in the usual way for measuring its lift, drag and pitching moment.

The arrangement of the air-screw shaft in its housing is disclosed in the scale drawing (Fig. 6). The propeller shaft, of tool steel hardened and ground, runs in ball-bearings, and is driven by the long flexible shaft or drive wire, to which it is joined by a sleeve coupling, into which both are threaded. At the

turbine end the drive wire threads into the rotor shaft. The copper tube around this wire has its upper end pushed into the bottom boss of the engine base, its lower into the end of the housing of the propeller shaft. It can slide in either if caused to lengthen by the heat of friction.

The engine, connected to a small air-screw, has been used at

FIG. 6.



Working drawing of air-screw bearing and drive.

speeds up to 20,000 rotations per minute. The running was uniform and void of vibration or overheating. A thin shrill siren note was emitted, not loud enough to cause discomfort. The shaft horsepower at 14,000 rotations per minute was a little over one with a single bucket wheel; a little over two with both wheels operating. The efficiency, being of minor importance, was not determined.

Periodicities, Solar and Meteorological. C. CHREE. (*Quarterly J. Royal Meteorol. Soc.*, April, 1924.)—In his address as president of the society, Doctor Chree lets fall an *obiter dictum* that may well be reflected upon by young American scientists, especially in view of Sir J. J. Thomson's kindly criticism of the lack of rigid mathematical training in the United States. "Having once been a mathematician myself, and having had a varied experience of other scientific subjects, I should like to express the opinion that no one is more likely to promote sound and continuous advance in any applied science than a first-rate mathematician, provided he has two qualifications, which do not necessarily go with mathematical gifts. The first is the possession of common-sense, the second is adequate familiarity with the subject to which the mathematics is to be applied."

A comparative study is made of sunspot frequencies from Wolfer's lists and the following terrestrial quantities determined by observations made at Kew, rainfall, mean temperature, daily range of temperature, hours of sunshine, potential gradient in the atmosphere, daily range of magnetic declination and the diurnal inequalities of declination and horizontal force. The correlation coefficients between sunspot frequency and the other quantities were calculated. If one of these were so related to the sunspot frequency that a change in it were in proportion to a change in the latter, then the coefficient would equal unity. The smaller the coefficient is the less is the likelihood that any connection exists between the two quantities under examination. It is in connection with the magnetic quantities that the largest values for the coefficient are found. For the daily range of declination the values of the coefficient for different groups of years vary from .76 to .95. The results found in the case of mean temperature are especially worthy of consideration. There is prevalent a belief that a high temperature on the earth goes with a minimum of sunspots. For the interval 1884–94 this is confirmed by a coefficient of .69, but for the fifty-one years, 1871–1921 it drops to .03, thus indicating that there is no probable connection. It may be likewise seen in the instance of other meteorological elements that for an extended term of years the coefficient is small, while for some decades it is quit large.

It stands out clearly "(1) that an important sunspot relation does exist in at least one terrestrial element (magnetism), (2) that, at least in these latitudes, the evidence for a connection between sunspot frequency and meteorological phenomena is of quite a different order from the evidence for a connection between sunspot frequency and terrestrial magnetism. . . . It may not be superfluous to explain that the decided relation between magnetic phenomena and sunspot frequency does not necessarily imply that sunspots themselves are immediately responsible for what happens on the earth. They may be only a system of increased solar activity, resulting in increased ionization in the earth's atmosphere." G. F. S.

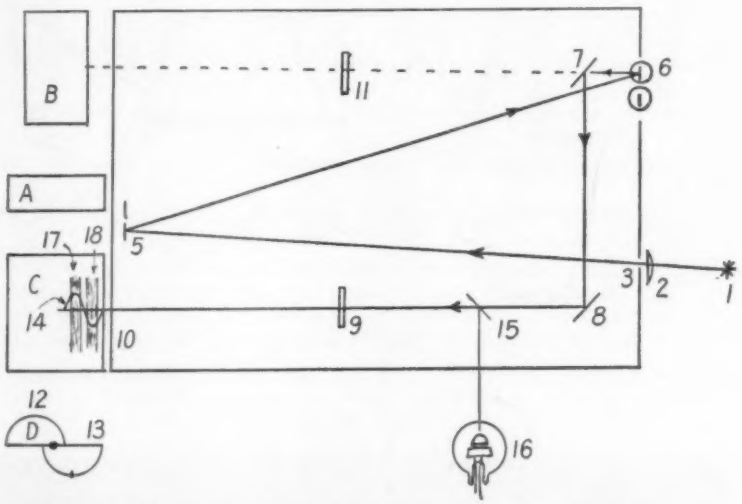
THE DISTRIBUTION OF LUMINOSITY THROUGHOUT A POTENTIAL CYCLE IN A NEON GLOW DISCHARGE LAMP.*

BY

ENOCH KARRER, Ph.D., and A. PORITSKY, M.S.

We have elsewhere [1] summarized some data showing how the luminosity in a neon glow lamp is distributed through the potential cycle. In the present paper we wish to describe in detail how these observations were made, since the method is

FIG. 1.



Schematic view of oscillograph showing the essential optical and electrical parts.

applicable in the study of other cases of luminescence, and is slightly different from methods heretofore used.

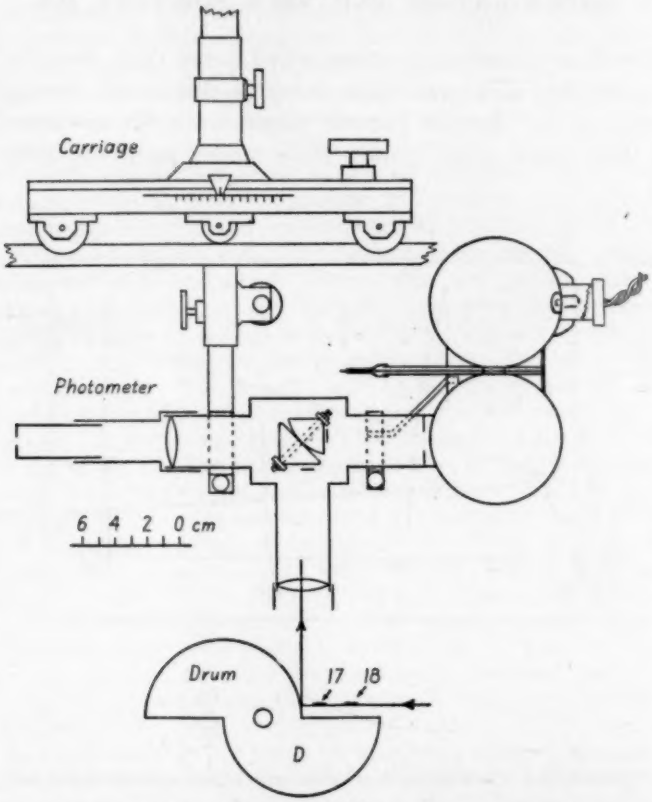
We have availed ourselves of an oscillograph (Siemens-Halske) that is ordinarily employed by electrical engineers to study wave form and power factor in a. c. circuits. Fig. 1

* Communicated by Doctor Karrer.

[1] *J.O.S.A.* and *R.S.I.* in press.

brings out the general disposition of the optical and electrical parts that concern us. *A* is a synchronous motor which drives the drum *B* carrying the photographic film, and the observing drum *C*. The latter has a specially designed contour in cross-section (shown in *D*) resembling the two halves of a cylinder displaced over a plane through the axis of revolution. The path of a ray of

FIG. 2.

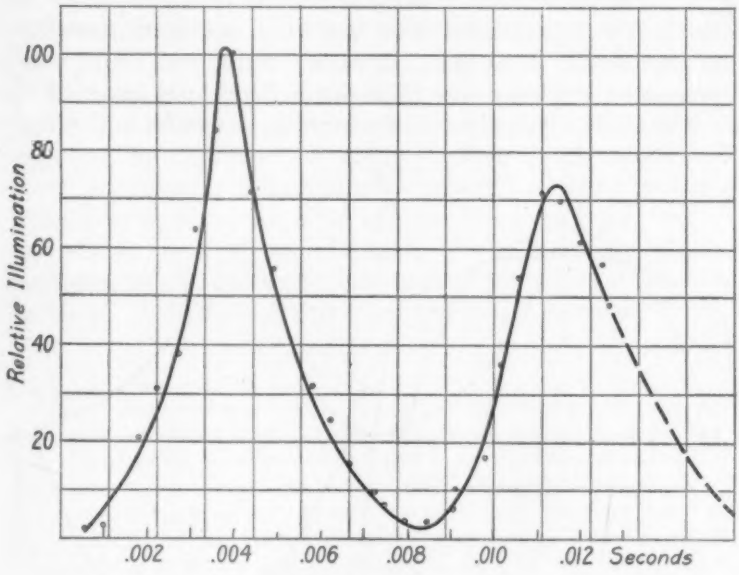


Disposition of photometer attached to carriage above oscillograph drum.

light from the arc 1, to the photographic or observing drum, is through lens 2, slit 3 to mirror 5, mirror 6 of the galvanometer element, mirror 7 (or cylindrical lens 11 for the photographic drum *B*), mirror 8, cylindrical lens 9, through aperture in wall 10, on to observing drum *C*, where it is reflected from the mat white convex surface 12. The plane surface 13 of

this drum is black. When the drum C rotates in synchronism with the galvanometer mirror 6, the light beam traces a stationary curve 14 in the plane in which its intersection

FIG. 3.



Relative illumination through a potential cycle.

with the surface of the drum vibrates. The glow lamp (16) in which we are interested illuminates, after interposition of a mirror 15, the drum through the narrow rectangular aperture

FIG. 4.

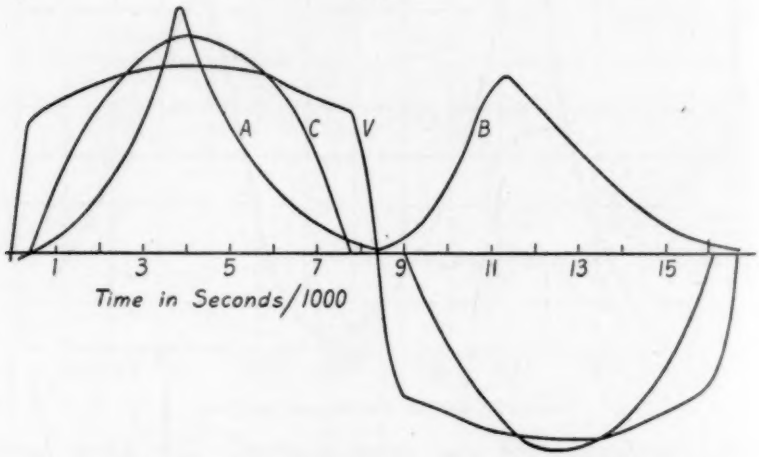
Oscillographic record of voltage, amperage and illumination.

in the screen 10. There will be a luminous streak across the drum C that may be observed by looking vertically downward. When the drum rotates in synchronism with the exciting potential

across the lamp there will apear two stationary streaks (17, 18)—one for each direction of current.

To measure the brightness across these luminous streaks 17 and 18, a photometer is mounted above the drum *D*, as shown in Fig. 2. The photometer is designed for measurement where low photic power is available, and has been described elsewhere.[2] This photometer is compact, extremely light, and could readily be attached to an ordinary photometer bench rod inverted that was adjustable vertically and horizontally by racks and pinions.

FIG. 5.



Curves showing instantaneous values of amperage, voltage and illumination.

The position of the photometer horizontally was correlated with the temporal position in the cycle by observations on the sinous trace of the a. c. voltage of the lamp. To make allowance for the change in reflectance of various parts of the drum surface, a standard non-flickering lamp was substituted for the glow lamp and a series of observations made across the drum while rotating.

In Fig. 3 is shown the curve which depicts the distribution of luminosity through the potential cycle of a neon glow lamp with acorn-like arrangement of electrodes. (This lamp is No. 2 of our previous paper, see ref. 1.) The inequality of the maxima is due to the inequality of the area of electrodes. The curves are slightly steeper on the ascent than on the descent. The curves show

[2] *J.O.S.A.*, **8**, p. 355, 1924.

practically complete darkness to either side of the maxima. We have an oscillogram reproduced in Fig. 4, which shows the voltage *v*, amperage *c*, and illumination *a*, *b*, for this lamp. The dark interval *d* there is very pronounced. These data plotted in the curves of Fig. 5 show more clearly the relationship between voltage *v*, amperage *c*, and illumination (proportional to photic power) *AB*.

It may be of interest to mention in shortest detail another method that we had considered that is more like methods used in observing fluorescence. A narrow white spot painted upon a black disc rotating synchronously with the exciting potential is illuminated by a narrow beam of light from the glow lamp which may rotate about an axis coincident with the disc axis. The brightness of the white spot is measured for different positions of the lamp. This method was more difficult to execute.

The Fluorescence of Æsculin Solutions. MISS M. B. KEARNEY. (*Phil. Mag.*, April, 1924.)—Equal masses of æsculin were dissolved in equal masses of water, ethyl alcohol, methyl alcohol, acetone and glycerine. The several solutions were exposed in quartz tubes to the light from a mercury arc and the intensity of the fluorescent light was measured at intervals. The initial intensity of the solution in water greatly exceeded that of the other solutions. In all solutions the intensity decayed with time. When the aqueous solution had been exposed for thirty minutes, the intensity of the emitted light was only about one-tenth as great as at the beginning. "Solutions in organic solvents require a much longer time of exposure to become completely transformed than those in water." For the solution in ethyl alcohol this time proved to be eighteen hours in contrast to one and one-half hours for the aqueous solution.

Æsculin powder was exposed to ultra-violet light for fifty hours and was then dissolved in water. The intensity of the fluorescent light was found to be just the same as that of a solution made from material that had not been exposed. It thus appears that "the presence of a solvent is essential for the transformation of æsculin."

"It has been verified that a solution can be made to fluoresce without being destroyed by exposing it either in an evacuated glass tube, or in a quartz tube surrounded by a transformed solution. In both cases, the extreme ultra-violet rays are cut off, showing that the decay of the fluorescent intensity is due to the wave-lengths in the extreme ultra-violet region."

An æsculin solution is easily obtained by stirring the sticky buds of the horse-chestnut tree in water. G. F. S.

The Artificial Disintegration of Atoms. G. KIRSCH and H. PETTERSSON. (*Nature*, April 26, 1924.)—Sir Ernest Rutherford and J. Chadwick in England and Kirsch and Pettersson in the "Institut für Radiumforschung," Vienna, have worked with such success upon this problem that it is now known that no less than fourteen elements liberate H-particles when under bombardment by α-particles. Alpha particles from radium C travel through helium and strike the element under investigation. A zinc sulphide screen is located in the experimental vessel so that the line joining it to the bombarded element forms approximately a right angle with the path of the α-particles. Owing to the impact of these particles, atoms of the element may be broken up and fragments may pass off sideways and cause scintillations where they strike the screen. Several precautions were taken to secure results. A microscope of high light-gathering power was used to observe the screen. Special shapes were given to the radium C source as well as to the element bombarded in order to get a maximum output of atomic fragments and moreover helium gas was employed because, when a stream of α-particles in this gas falls on a target, "the range of α-particles scattered under 90° is nil." Thus whatever particles were detected at the screen they could not be identified with α-particles scattered by the target, and, furthermore, atomic fragments of short range could be sought. The helium was provided by the Bureau of Mines, Washington. Two very weighty results have been attained by the method just described: (1) "Carbon, examined as paraffin, as very pure graphite, and finally as diamond powder, gives off H-particles of about 6-cm. range. Their number, which has not yet been accurately determined, is of the order 200 per 10^7 of the α-particles producing the disintegration," and (2) "other experiments recently made seem to prove that oxygen is also disintegrable and gives off α-particles of 9-cm. range in the forward direction. If this result is confirmed by further experiments now proceeding, it would furnish the first example of α-particles as a product of artificial disintegration." We have clearly come a long distance since the day when Bancroft delivered his address before the A. A. A. S. on "The Transmutation of the Elements."

G. F. S.

The Electric Furnace Spectrum of Titanium in the Ultra-violet. A. S. KING. (*Astrophys. Jour.*, April, 1924.)—The furnace lines of the metal in the visible spectrum have already been listed and published. This paper gives the ultra-violet spectrum as far as λ2600. In it are 785 lines for 333 of which new wave-lengths are given. Either titanium carbide or c. p. titanium powder was used. Temperatures of 2000°, 2250°, and 2500° C. were used to study the effect of a change of temperature on the lines. An actual count showed that the number of enhanced lines grows larger as the wave-length grows less. For example, from 4500 to 4800 Å. there are only 8, while from 2700 to 3000 Å. there are 168. G. F. S.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

PULP AND PAPER FIBRE COMPOSITION STANDARDS.[1]

By Muriel F. Merritt.

[ABSTRACT.]

REFERENCE Standards, Showing the Color Reactions of Common Papermaking Fibres and Standard Fibre Mixtures with Various Stains for Use in Identification and Estimation of Fibre Composition of Paper.

In standardizing the micro-analysis of paper fibres there are no colored plates of 100 per cent. pure pulps or standard percentage mixtures of standard pulps. The need for such plates is felt by beginners and laboratory workers in micro-analysis. The advantage of the colored micrograph over the ordinary photomicrograph is that the former more nearly represents the fibres as observed, since it appeals to one's color sense. Standard pulps and colored plates of standard fibre mixtures greatly aid in the identification of fibres by color and form, and the determination of percentage composition can then be made more easily. The publication covers eight fibre compositions, illustrating pure pulps and mixtures, with their color reactions. These fibres are rag (linen and cotton), sulphite (coniferous), soda (deciduous), groundwood (coniferous), sulphate (coniferous), jute, manila, and esparto. The fibres selected were those of most importance to the paper industry. Standard pulps and pulp compositions used by the Bureau of Standards for comparison work in estimation of fibre content were selected for the micrographs, several slides being prepared for each drawing. Different stains were used to bring out as many characteristics as possible. Four stains particularly useful in staining fibres are: Delafield's hematoxylin, 1 per cent. solution of malachite green, Herzberg stain and the Lofton-Merritt stain for unbleached sulphite and sulphite pulps.

The formulas for the stains are given in the text. The first three stains listed are used in a dilute form. Hematoxylin, use one drop of stain to two of water; malachite green and Herzberg

* Communicated by the Director.

[1] Technologic Papers, No. 250, price fifteen cents.

stain, use one drop of stain and one drop of water. For all stains, leave on the fibres two minutes, then rinse with water. A photograph of the camera lucida outfit is shown. A magnification of 200 gave the best definition for drawing with the camera lucida. As reproduced, the micrographs are about 50 magnification. Where practical, fields were drawn as they occurred in the slide, care being taken to get as many representative fibres as possible typical of the pulp or pulp mixtures. For the color medium, water colors were employed. In order to correctly reproduce color reactions of the stained fibres, rag filter paper cut in strips was painted with the approximate colors sought, then matched under the microscope by daylight with the stained fibres. If the color of the paint was not standard, the paints were mixed until the standard color was produced. The Herzberg stain colors the fibres yellow, red or blue depending on the fibres. Colors used to match the Herzberg yellow, in Japanese colors, brilliant yellow, deep yellow, and the English water colors, burnt umber, burnt sienna, olive green, and van dyke brown. Colors used to match the Herzberg red: English water colors, brown madder, rose madder, and prussian blue. Colors used to match the Herzberg blue: English water colors, prussian blue, brown madder, and rose madder. Colors used to match the Lofton-Merritt stain purple: English water colors, mauve, and malachite green dye solution. Lofton-Merritt stain blue-green was secured with English water colors, prussian blue and malachite green dye solution.

NATIONAL STANDARD PETROLEUM OIL TABLES.[3]

[ABSTRACT.]

THE circular entitled "National Standard Petroleum Oil Tables," prepared by the U. S. Bureau of Standards and approved by the American Petroleum Institute, the Bureau of Mines, and the Bureau of Standards, contains tables based on the results of an investigation of American petroleum oils carried out by the Bureau of Standards, published as Technologic Paper No. 77, and supplemented by additional investigation of the rate of expansion of oils at temperature beyond the range originally covered.

The arrangement of the tables and also the gravity and temperature range covered have been given careful consideration both

[3] Circular No. 154, price thirty cents.

by the bureau and by a special committee appointed by the American Petroleum Institute to represent the petroleum industry.

In order to overcome the confusion that has existed in the petroleum industry by reason of the two so-called Baumé scales for light liquids, the American Petroleum Institute, the Bureau of Mines, and the Bureau of Standards in December, 1921, agreed to recommend that in the future only the scale based on the modulus 141.5 be used in the petroleum-oil industry and that it be known as the A. P. I. scale. The relation of degrees A. P. I. to specific gravity is expressed by the formula

$$\text{Degrees A. P. I.} = \frac{141.5}{\text{sp. gr. } 60°/60° \text{ F.}} - 131.5$$

The tables given apply to petroleum oils, both crude and refined, produced in the United States. Each grade of oil, gasoline, illuminating oil, lubricating and fuel oil, etc., falls into its proper place in the tables by reason of its specific gravity.

The arrangement and application of the tables follow:

Table 1.—Reduction of observed degrees A. P. I. to degrees A. P. I. at 60° F. This table shows the degrees A. P. I. at 60° F. of oils having at the observed temperatures the degrees A. P. I. indicated. For example, if the observed degrees A. P. I. at 78° F. is 20.0 the degrees A. P. I. at 60° F. will be 19.0. Intermediate values can be conveniently interpolated.

Table 2.—Volume at 60° F. occupied by unit volume at indicated temperature. This table shows the volume occupied at 60° F. by a quantity of oil of any A. P. I. gravity at 60° F. occupying unit volume at the indicated temperatures. For example, if at 60° F. the A. P. I. gravity of the oil is 22, one gallon of this oil measured at 105° F. will have a volume of 0.9822 gallon at 60° F.

Table 3.—Reduction of observed specific gravities to specific gravities at 60°/60° F. This table shows the specific gravity at 60°/60° F. of oils having at the observed temperatures the specific gravity indicated. For example, if the observed specific gravity at 95° F. is 0.740 the specific gravity at 60°/60° F. will be 0.7553.

Tables 4 and 5 give the relation between specific gravity, degrees A. P. I., pounds per gallon, and gallons per pound.

Table 6 gives the degrees A. P. I. (modulus 141.5) corresponding to degrees Baumé (modulus 140).

Experiments on the Artificial Disintegration of Atoms. GERHARD KIRSCH and HANS PETTERSSON. (*Phil. Mag.*, March, 1924.)—The success of the attempt to bring about the disintegration of the atom was in a large degree due to the discovery by one of the authors of a new way of getting strong preparations of radium C. A conical plug of invar steel was ground to fit into the neck of a quartz vessel containing radium emanation. The lower end of the plug was kept in liquid air. The emanation froze upon the upper end of the plug the heat of which had been conducted away, and there it remained for some hours to permit the active deposit to accumulate. The temperature of the steel then rose to room temperature while the emanation was being pumped off. The yield of radium C could be almost doubled by placing a piece of thin metallic foil on the emanation as soon as it settled as a solid on the steel.

By the use of the intense source of α-rays thus obtained, it was found that hydrogen particles were produced by the bombardment of beryllium, magnesium and silicon. It is interesting to note that Rutherford and Chadwick in a March, 1924, number of *Nature* announced that they too had succeeded in getting hydrogen by the action of α-particles on silicon and magnesium.

Kirsch and Pettersson find that "for lithium the evidence is less conclusive." If a similar result is obtained at all from Sc, Va, Co, and As its manifestation is much weaker than in the case of aluminum.

It thus seems definitely proved that hydrogen can be derived from at least fourteen other elements by bombarding them with α-particles.

G. F. S.

A New Determination of the Normal Boiling Points of Oxygen, Nitrogen and Hydrogen. F. HENNING and W. HEUSE. (*Zeit. f. Physik.*, Vol. 23, Nos. 1 and 2.)—An exact knowledge of these temperatures is needed for the fixing of the temperature scale. The recent, reliable determinations give results that fall within a small fraction of a degree of one another but to the physicists in the Physikalisch-Technische Reichanstalt it seemed worth while to seek even greater certitude. They used helium as the thermometric substance in preference to hydrogen, because there is less chance of error in reducing the readings to the thermodynamic scale. A special arrangement was employed to avoid error in reading the manometer. The following temperatures on the thermodynamic scale are found for the boiling points under one atmosphere: Oxygen, $-183.00 \pm 0.02°$; nitrogen, $-195.81 \pm 0.02°$; hydrogen, $-252.78 \pm 0.02°$. As an illustration of the accuracy attained, let it be said that with oxygen the boiling points measured by two different helium thermometers at pressures of 750.2 and 773.2 mm. Hg, respectively, were recorded as $-183.11°$ and $-182.87°$.

G. F. S.

NOTES FROM NELA RESEARCH LABORATORIES.*

LONG WAVE-RADIATION FROM THE QUARTZ MERCURY ARC AND FROM CORED CARBON ARCS.

By E. F. Nichols and J. D. Tear.

RUBENS AND VON BAEYER, using the focal isolation method of Rubens and Wood and an interferometer of the Fabry and Perot type equipped with quartz plates, identified two long wave-lengths in the spectrum of the quartz mercury arc. According to later and more accurate measurements by Rubens with a grating, the two wave-lengths are 210 and 324μ.

This experiment was repeated by the authors, using the short electric wave radiometer and substituting for the focal isolation lens system screens of fused quartz and black photographic wrapping-paper. An interference curve obtained with radiation from the mercury arc filtered through two thicknesses of paper and 2 mm. of fused quartz resembled closely that obtained by Rubens and Von Baeyer, though in the former curve there was evidence of a somewhat larger proportion of short wave-radiation. When, however, the number of paper screens was increased to four, the thin fused quartz plate replaced by one 8 mm. thick and the interference curve repeated, there appeared a sharp maximum corresponding to the wave-length of 420μ. Though components of shorter wave-lengths were present, their amplitudes were much smaller than in the earlier curves and the 420μ component was clearly predominant.

Dielectrics, which are opaque in the extreme infra-red and transparent to electric waves in general, show increasing transmissions for waves of this length. Thus rock salt, fluorite, fused quartz and glass show greater transmission for 420μ than for 324μ. A sheet of glass 0.85 mm. thick which transmitted less than 1 per cent. at 324μ transmitted 13 per cent. of the 420μ radiation.

A preliminary search was made for long waves in the arc spectra of various metals. The metals were placed in a hole drilled in the positive carbon and the arc operated at approximately 25 amperes. The hot carbon electrodes were carefully screened

* Communicated by the Director.

from the radiometer by a water diaphragm and the radiation from the arc after passing through the 8 mm. fused quartz plate and the four sheets of black paper was brought to a focus upon the radiometer vanes by a concave mirror.

The carbon arc in air alone gave small positive deflections. When mercury was added the deflections were nearly as large as those obtained from the mercury arc in quartz, though they were not sufficiently steady for wave-length measurements. Copper, iron, tungsten, tantalum, and molybdenum gave deflections no greater than the carbon arc alone. Zinc, lead, tin, bismuth, nickel, and calcium gave definitely positive deflections, zinc about one-third that due to mercury and the others less in the order named.

The deflections were evidently determined more by the volatility of the metal and consequently by the quantity of vapor in the arc than by the metal's radiating properties, and were too irregular to permit measurements with the present apparatus.

LUMINOUS EFFICIENCY OF PHOSPHORUS GLOW.

By E. Q. Adams.

No measurements of the efficiency of production of light by chemical reactions proceeding at ordinary temperatures appear to have been published hitherto. Such a measurement in the case of the glow of phosphorus was made by saturating a stream of specially purified atmospheric nitrogen with phosphorus vapor by bubbling it through a suspension of phosphorus in refined cotton-seed oil. The stream of saturated gas was allowed to escape into the air, forming a cone of luminosity resembling in appearance the inner cone of the Bunsen flame.

The brightness of the "flame" was measured by matching it by an annulus of filter paper illuminated by a miniature lamp adjustable with respect both to current and distance from the annulus. Approximate color match was secured by the interposition of a suitable yellow-green light-filter. From the brightness and projected area, the total light flux was calculated.

The power input was calculated from the measured rate of flow of the nitrogen, the heat of combustion of phosphorus, and the measurements by Centnerszwer of the vapor pressure of phosphorus at various temperatures.

The ratio of light flux to power input was approximately one lumen per kilowatt, and not greatly different at 25° and at 40° C.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

SOME UNRESOLVED FACTORS IN JELLY STRENGTH DETERMINATION.[1]

By S. E. Sheppard and S. S. Sweet.

THIS paper deals with several variable factors in jelly strength determinations. Among them the dimensions of test pieces is discussed. It is shown that shorter pieces have an apparently higher elasticity up to a certain limit, a length of 7.5 cm. The data shown confirm the work of Maurer and Bjerkén that there is no change in the volume of jelly during elongation. The end effect in the torsion instrument is also measured and shown to be negligible with cylinders over one inch in height. Gelatins were made up and tested on both the plunger tester and the Smith tester, giving proportional results. The relation of jelly strength to H-ion concentration is also discussed, a maximum at a p_H of 7 to 9 being checked repeatedly, but not at a p_H of 4 to 5.

OPTICAL COLLINEATION INDEPENDENT OF METRICS.[2]

By L. Silberstein.

THE optical collineation, familiar from geometrical optics as the representation of Möbius-Abbe, is set up and developed projectively, *i.e.*, without making use of the metrical concepts of distance or angle and, therefore, also of orthogonality or parallelism. The treatment is based entirely on the axioms of projective geometry. The collineation in question is defined graphically, implying straight-edge operations only, and then translated into formulas by means of a projective vector algebra constructed some time ago by the author. The algebraical as well as the graphical representation of the optical collineation, thus generalized non-metrically, is discussed in some detail.

* Communicated by the Director.

[1] Communication No. 197 from the Research Laboratory of the Eastman Kodak Company. Published in *Ind. Eng. Chem.*, 16, 593, 1924.

[2] Communication No. 198 from the Research Laboratory of the Eastman Kodak Company. Published in *J. Opt. Soc. Amer.*, 8, 675, 1924.

Dezincification of Brass.—Considerable study has been given to this topic which has importance in chemical operations. Abrams (*Trans. Amer. Electrochem. Soc.*, 1922, **42**, 39) found that the process is not the direct solution of the zinc, but the solution of the whole alloy with the subsequent deposition of the copper, and that there is no dezincification unless a membrane is present to hold the copper-rich solution in contact with the brass. C. F. Nixon, a senior student in the Chemical Engineering Department of the University of Wisconsin presented at the forty-fifth meeting of the American Electrochemical Society in April, 1923, a paper giving further results in the study of the subject starting with Abrams' view. It was found that the presence of oxygen or highly ionized copper is necessary to initiate solution. Some copper salts, such as acetate, lactate, bromate and perchlorate do not promote dezincification. Brass is not the only alloy susceptible of removal of one constituent. Copper-aluminum (70–30), manganese-copper (25–75) and cadmium-magnesium (85.7–14.3) were found to be subject to selective erosion. It was found that when the amount of copper is 90 per cent. or over, dezincification is not likely to occur. Monel metal and German silver are resistant. Tin in brass slows down the dezincification materially. Antimony has little beneficial effect; nickel and arsenic brasses appear promising and worthy of further study. H. L.

Contributions to the History of the Spectacle Trade from the Earliest Times to Thomas Young's Appearance. M. VON ROHR. (*Trans. Optical Soc.*, Vol. 25, No. 2.)—In this most interesting article, replete with curious antiquarian knowledge, the development of the manufacture in the Low Countries, in Germany, Spain and Italy is treated. Perhaps the earliest suggestion of the use of lenses to remedy the defects of the eye is found in the "Opus Majus" of Roger Bacon, where he recommends for old and weak-eyed persons the use of plano-convex lenses. The first picture of spectacle-helps, painted in 1352 by Treviso, shows both a single lens mounted on a handle and also two such lenses with the handles riveted together. The early prices of spectacles were not excessive. Before 1500 a pair of negative spectacles was sold at the Bavarian convent of Tegernsee for about 7 farthings and in 1583 even lower rates were quoted, though Albrect Duerer had to pay as much as 9½ farthings for his reading glasses.

As to the origin of bifocal glasses, "The combination of two divided glasses by means of the mounting was known to C. Hertel in 1716. In 1784–85 Benjamin Franklin described his spectacles made in such a way." "Thomas Young not only mentioned the use of divided (bifocal) glasses at a very early date, but was the first to apply them to scientific purposes." G. F. S.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

THE EFFECT OF CERTAIN DELEADING AGENTS UPON HYDROLYSIS IN THE DETERMINATION OF REDUCING SUGARS IN LEATHER AND TANNIN EXTRACTS.[1]

By I. D. Clarke and R. W. Frey.

[ABSTRACT.]

In the determination of reducing sugars by methods using a large quantity of lead acetate for clarification and a salt of a little ionized acid, such as oxalic or phosphoric, for deleading, due consideration should be given to the ratio between the quantities of these reagents present and the quantity of acid added for hydrolysis. By double decomposition the acid added for hydrolysis is partially replaced by the weak acids, acetic and oxalic, or acetic and phosphoric, as the case may be, and consequently hydrolysis may be incomplete, depending upon the quantities of the salts present.

It is shown that by the method of the American Leather Chemists Association for reducing sugars in leather, using 5 c.c. of concentrated hydrochloric acid for hydrolysis, widely varying results may be obtained, depending upon the quantity of deleading agent present. The use of a greater quantity of acid eliminates these variations without requiring careful control of the amount of deleading agent. It is shown also that with but 5 c.c. of acid low results are sometimes obtained, even though just the required minimum of deleading agent is used.

The determination of reducing sugars in tannin extracts presents a difficulty in that conditions, such as concentration of acid and period of boiling, for optimum hydrolysis vary with the nature of the material. In some cases over-hydrolysis and consequent loss of sugars may readily occur. It may be necessary with tannin extracts to run a graded series of determinations for each sample and take the highest value as correct.

* Communicated by the Chief of the Bureau.

[1] Published in *J. Am. Leather Chemists Assoc.*, 19 (May, 1924) : 237.

CYSTINE DEFICIENCY AND VITAMIN CONTENT OF THE LENTIL, LENS ESCULENTA MOENCH.[2]

By D. Breese Jones and Joseph C. Murphy.

[ABSTRACT.]

THE proteins of the lentil, *Lens esculenta*, like those of the beans of the genus *Phaseolus*, are limited in their nutritive value by a deficiency of cystine. Albino rats fed a diet containing 66 per cent. of raw lentil declined in weight promptly and lived, on an average, only thirty-three days. Somewhat better results were obtained when the lentil had been cooked. On the same diet to which 0.36 per cent. of cystine had been added, the animals made from fair to very good growths.

Two grams daily of lentil furnish about the minimum quantity of vitamin B required for the normal growth of the albino rat, while the quantity needed to furnish the required vitamin A is not far from 2.5 grams.

THE VISCOSITY OF NATURAL AND RE-MADE MILK.[3]

By Oscar L. Evenson and Leslie W. Ferris.

[ABSTRACT.]

THE relation of viscosity to the total solids is shown by means of the expression $\frac{V-1}{T.S.}$ in which

$$V = \frac{\text{Time of flow of milk} + \text{specific gravity of milk}}{\text{Time of flow of water} + \text{specific gravity of water}}$$

and $T.S.$ = total solids expressed as parts by weight of milk solids per gram of fluid milk. The values for $\frac{V-1}{T.S.}$ for re-made milk were in many cases considerably higher than those for natural pasteurized milk.

The viscosity of milk as determined is, to a certain extent, dependent upon the temperature at which the milk has been held.

The viscosity is decreased slightly by pasteurization at 62–65° C. for thirty minutes, but is decidedly increased by heating to 75–80° C. for the same length of time.

Homogenization at a high pressure affects the viscosity, while the emulsor has little or no effect.

[2] Published in *J. Biol. Chem.*, 59 (March, 1924) : 243.

[3] Published in *J. Dairy Sci.*, 7 (March, 1924) : 174.

By means of a high-speed centrifuge it was possible to throw out milk solids from both natural and re-made milk to such an extent as to lower the values for the relation of viscosity to the total solids as compared with those for the original milk. The sediment obtained from re-made milk differed in quantity and character from that of natural milk.

The Radiation of Light. H. A. Lorentz. (*Nature*, April 26, 1924.)—Holland has contributed more to the scientific life of the world than would be her quota were population or area the basis of expectation. The author of this discourse, delivered at the Royal Institution, is one of her sons of whom she has the best reason to be proud. His work in physics is at once profound and illuminating. In this lecture both of these qualities are to the fore.

Newton's understanding of the phenomena of light is discussed and it is shown how in his mind the corpuscular theory and the undulatory theory are intertwined. Then about a century ago the undulatory theory became supreme, to be transformed by Maxwell into the electromagnetic theory. "In these last ten or twenty years physicists have been led to ideas, not exactly the same as Newton's, but still more or less similar to the notions of the corpuscular theory." In the place of the corpuscles of Newton we now have the quanta of Planck "definite amounts of radiation, the magnitude of which is proportional to the frequency n, or number of vibrations in unit time, so that it can be represented by hn, where h is a constant. In Bohr's theory of spectral lines these minute amounts of energy play a fundamental and most important part; one of his assumptions being that light is not emitted in quantities of any magnitude, but in a greater or smaller number of full quanta that are radiated successively, one at a time."

Professor Lorentz next turns to the consideration of the volumes of the quanta. When light of suitable wave-length falls on a plate of a rightly chosen substance, it sets free electrons each one of which possesses an amount of energy equal to the quantum for the light used. This equality holds true even if the plate be moved away from the source of light. A smaller number of electrons are ejected than before, but each has as much energy as in the nearer position. "This can be easily understood if the quanta are confined to small spaces, so that the electron can catch at once a whole quantum, whereas, if a quantum is spread out over a considerable extent, it is very difficult to see how an electron is to get hold of it." Thus the facts of photo-electricity seem to require a quantum of exceedingly small extension. On the other hand, the phenomena of interference demand just as imperatively that the quantum shall have a large size. Interference fringes are not produced by the interaction of light from

two or more independent sources. To get them, light from a single source is divided into two or more parts and these parts are brought to the same point. Now a quantum is emitted by one atom and there is no reason to think that a group of atoms emit their quanta in any systematic way like fire-flies flashing in concert. "Hence when we observe an interference phenomenon, one quantum taken by itself must be able to produce it, and this will enable us to draw some conclusions concerning the extension of a quantum in different directions. In certain experiments made with highly homogeneous light, interference fringes have been observed, produced by rays the paths of which differed by more than a million of wave-lengths. This means that there was a regular succession of more than a million of waves, and, since all these waves must be contained in one quantum, the length of a quantum in the direction of propagation must have been more than, say, 50 cm." To get the lateral extent of the quantum, recourse is had to Michelson's method of measuring the diameter of the stars by the interference of two rays from the star which, at the telescope, are about 10 m. apart. Thus from the data of interference it would appear that a quantum occupies a volume whose diameter is not less than 10 m. and whose depth is at least 50 cm. This, of course, flatly contradicts the conclusions drawn from photo-electricity. The phenomena of interference and of photo-electricity are so well established that conclusions logically drawn from one cannot in the end be incompatible with those drawn from the other. "It must after all be possible to reconcile the different ideas. Here is an important problem for the physics of the immediate future. We cannot help thinking that the solution will be found in some happy combination of extended waves and concentrated quanta, the waves being made responsible for interference and the quanta for photo-electricity." G. F. S.

The Distribution of Colloidal Particles. E. F. BURTON and J. E. CURRIE. (*Phil. Mag.*, April, 1924.)—"The problem of the distribution of colloidal particles was first brought into prominence by the work of Perrin, who showed that for regions very near the surface of a given volume of solution the law of the distribution of the particles is analogous to that regulating the distribution of molecules of gas in the atmosphere. Although the original experiments were carried out for distances up to only one-tenth of a millimetre, the impression that it holds for all distances has got abroad. Theoretical considerations show that the law cannot hold for distances even of the order of a few centimetres." Very careful experiments extending over four months were conducted with colloidal solutions protected from changes of temperature that might produce convection currents. After standing for this considerable period the concentration of the solutions at different levels was determined. In the same solution no definite difference of concentration was found, no matter whether the layer was 9 or 132 cm. below the surface. G. F. S.

NOTES FROM THE U. S. BUREAU OF MINES.*

TEMPERATURES IN LOCOMOTIVE CABS IN TUNNELS.

By S. H. Katz and E. G. Meiter.

A STUDY was completed which gives authoritative information on atmospheric conditions in cabs of locomotives when passing through tunnels on the Chesapeake and Ohio Railroad in Virginia and West Virginia. This work was undertaken at the request of the railroad company, in order to determine the causes of high temperatures in the cabs and the exact effect on the men of heat, gases and smoke liberated by the immense locomotives in passing through the long series of tunnels.

It was found that the carbon monoxide might become a considerable hazard only in the event of a train being stalled or delayed. Smoke respirators of approved type were found to afford good protection from irritating gases. Recommendations were also made for alleviating discomfort from hot humid air in the tunnels. Further details are given in a forthcoming publication of the bureau.

PORTABLE POWER PLANT FOR GASEOUS COAL MINES.

By L. C. Ilsey.

ON May 5th, the Mancha power truck was approved by the Department of the Interior for safe use in gaseous and dusty coal mines. The development of the safety features of this truck, the first portable power plant to be approved for underground use in mines with an explosion hazard, is largely due to the careful and thorough testing and patient study by bureau engineers to determine and eliminate the weak points in the design as submitted by the manufacturers. This portable power plant is used for operating coal-cutting machines and is unique in that it works on a storage battery, thereby eliminating the need of an electric feeder circuit to the coal face. This is important because sparking from the electric wiring is one of the chief sources of electrical accidents in mines. A wider application of the storage battery may eventually be the solution of this problem by doing away with the need for trolley wires in gassy mines.

* Communicated by the Director, Bureau of Mines.

TESTS ON THE LEAKAGE OF MINE VENTILATING DOORS.

By J. W. Paul, G. E. McElroy, and H. P. Greenwald.

IN the course of experiments on coal-mine ventilation factors which the Bureau of Mines has been conducting for the past two years at its experimental mine near Bruceton, Pa., tests were made in order to determine the leakage of two air-locks which had been placed in the mine.

Each air-lock consisted of two doors, set in concrete frames and closed fairly flush with the door-jams. The main source of leakage was along the sill where there was a narrow clearance opening, in addition to 4 to 6-inch gaps at the rails. However, this source of leakage was reduced somewhat by 6-inch canvas strips nailed to the bottom of each door on the pressure side. These doors represent minimum leakage under mine conditions. The results showed that with both doors closed at both air-locks, the leakage was 3.5 to 8.1 per cent.; one door closed at each air-lock, 5.2 to 13.0 per cent.; seal at outer air-lock, both doors closed at inner air-lock, 0.7 to 3.7 per cent.; seal at outer air-lock, one door closed at inner air-lock, 2.1 to 4.2 per cent.

An average leakage of 2 to 3 per cent. would seem to be a minimum for the best of mine doors under moderate pressure conditions, even with what would ordinarily pass for a good door and frame; lack of efficient provision along the sill—such as wet canvas flaps—may easily permit leakages of 5 to 10 per cent. Further details are given in Serial 2602 recently issued.

ASSAY RETORT STUDIES OF TEN TYPICAL OIL SHALES.

By W. L. Finley, J. W. Horne, D. W. Gould, and A. D. Bauer.

IN a coöperative study by the Bureau of Mines and the State of Colorado, the results of analyses of the oil and gas produced from a number of oil-shale samples from the principal deposits of Colorado and other oil-shale States, are compared with samples from Scotland and Australia, where the oil-shale industry has had its greatest commercial development, and also with a sample from Brazil where extensive oil-shale deposits are found.

The Bureau of Mines assay retort was used in all of the tests. Each shale was heated at five different rates of uniform, controlled oil production, in order to determine the changes in the distillation

products under different retorting conditions. The rates used were 1 c.c., 0.5 c.c., 0.33 c.c., 0.25 c.c., and 0.2 c.c. per minute. All other conditions were kept constant. After all the oil had distilled, heating of the shale was continued for thirty minutes at the same standard temperature. This method gave gas yields which are comparable, but they do not represent the maximum yields obtainable. Enough runs were made at the rates of 1 and 0.2 c.c. per minute to obtain enough oil (300 c.c.) for the regular distillation. In the tests at the intermediate rates only enough oil (60 c.c.) was produced for a distillation in a modified 100 c.c. Engler flask, which has the side-arm one inch higher than the standard flask. The oil was distilled through a fractionating column, 4½ inches long, of iron "jack" chain, and the distillate collected at the rate of one drop per second.

Serial 2603, containing detailed tables of the results of the distillation tests, has been recently issued by the Bureau.

All of the shales examined yielded more oil at the fast rate, that is, 1 c.c. per minute, than at the slow rate, 0.2 c.c. per minute, but at the slower rates the quality of the oils was superior to that of the oils produced at the faster rates.

The Colorado shales, all of which are from the Green River formation, have more resemblance to each other than to the shales from the other regions, yet there is enough variation in the nature of the products to distinguish each shale from the others. The Australian and Scottish shale oils showed the highest saturation of any of the oils tested. This seems to indicate the superiority of the oils produced from the foreign shales. The oils from the Scottish, Nevada and Australian shales were similar to the crude petroleums of the so-called "paraffin base"; the Kentucky shale oil was rich in asphalt, and the Colorado and Utah shale oils tested were intermediate.

Experimental Proof of the Quantizing of Direction in the Magnetic Field. The Magnetic Moment of the Silver Atom. W. GERLACH and O. STERN. (*Zeit. f. Physik*, Vol. 9, 1922.)—In an electrically heated vessel silver was evaporated. A beam of the gaseous atoms of metal escaped through a hole 1 sq. mm. in area. After moving for 2.5 cm. it fell on a screen with an aperture of .003 sq. mm. The portion of the original beam that came through this travelled 3.3 cm. and then met a screen with a slit in it, .8 mm. long and .03 or .04 mm. wide. A vacuum of about .00001 mm. of mercury was maintained in the entire space included in the apparatus.

The slit is just at the beginning of the sharp edge of a wedge-shaped electromagnet. The tiny beam of silver atoms, after passing through the slit, moves parallel to this edge, which is 3.5 cm. long, at less than .5 mm. from it. At the further end of the edge the ray strikes upon a glass plate on which it forms a deposit. The process was continued for eight hours and even after this length of time the quantity of silver deposited was so small that a method of development needed to be used to bring it into evidence. When the magnetic field was absent, there was revealed a strip of deposit 1.1 mm. long with a width varying from .06 to .1 mm. With the magnetic field present the shape of the deposit is very different. In the middle of the area there is a portion of the glass showing no deposit at all. This has the form of a section of a double convex lens taken parallel to the axis. In the direction away from the magnetic edge there is a deposit bordering the unaffected middle space and there is a similar deposit on the side toward the edge. Right opposite the edge appears a projection of deposit like the boss of a shield. "The impressions show that the ray of silver atoms in a non-homogeneous magnetic field is divided into two parts, one of which is attracted to the edge of the magnetic pole while the other is repelled from it." There was no trace of atoms that were neither attracted nor repelled. The attraction was stronger than the repulsion.

In commenting on this highly important experiment, J. C. McLennan, in his presidential address before the Section of Mathematics and Physics of the B.A.A.S. last September, said: "From these results it was concluded that all the silver atoms in the stream of vapor possessed a definite magnetic moment, and that while the atoms were passing through the magnetic field their magnetic axes had two distinct orientations in space." In further interpretation of the phenomena observed this additional citation is worth while: "One of the most surprising and interesting developments of the quantum theory is that which shows that quantum numbers determine not only the size and form of the electron is Keplerian orbits in atoms, but also the orientation of these orbits in space with regard to a favored direction such as that provided by an interatomic or by an external magnetic or electric field of force. For any arbitrary value of the azimuthal quantum number k, the simple theory shows that there are exactly $(k + 1)$ quantum positions of the orbital plane characterized by whole numbers. For example, if $k - 1$ the normal to the orbit may be either parallel to the direction of the controlling field or at right angles to it." (Should this not be at 180° to it?) For silver k does equal 1. Hence the atoms of this metal set themselves in one of the two possible positions and accordingly form parts of one or other of the two rays into which the original ray is divided.

The two authors made a subsequent study of the rate of variation of the magnetic field and came to the interesting additional conclusion that "the magnetic moment of the normal silver atom in the gaseous state is one Bohr magneton." G. F. S.

THE FRANKLIN INSTITUTE.

MINUTE OF THE BOARD OF MANAGERS RELATIVE TO THE DEATH OF DR. HARRY F. KELLER.

At the meeting of the Board of Managers held Wednesday, April 9, 1924, the following preambles and resolutions were passed:

Whereas: In the death of Dr. Harry F. Keller, member of the Board of Managers, the Institute has lost one of its most faithful friends and able supporters, and

Whereas: A deep sense of personal loss is felt by every member of the Board in the death of a friend and co-worker whose qualities of heart and mind endeared him to all, therefore be it

Resolved: That the Board of Managers of The Franklin Institute records with profound sorrow the death on February 5, 1924, of its esteemed and distinguished member, Dr. Harry F. Keller, whose activities as a teacher and fruitful worker in the domain of physical science have been of immeasurable value to the community and to the Institute, and be it

Resolved Further: That the sympathy of the Board be extended to Mrs. Keller and the family in their great bereavement, and be it

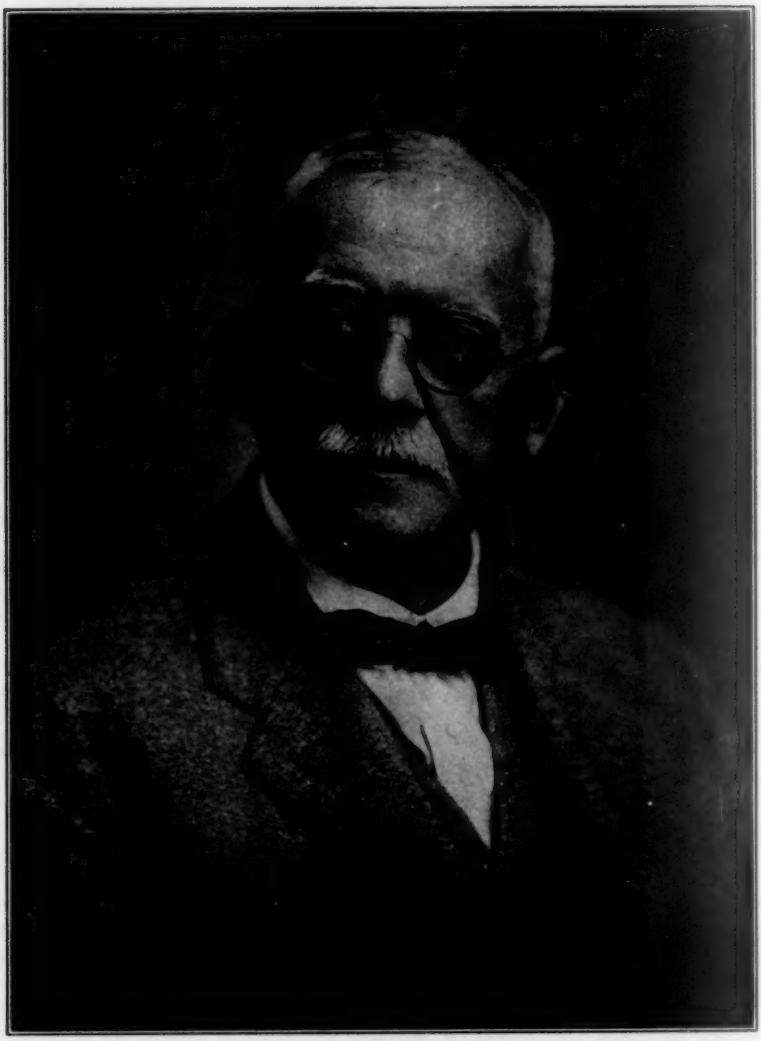
Resolved Further: That a copy of the above preambles and resolutions be sent Mrs. Keller and a copy, together with the following biographical sketch, be published in the Journal.

BIOGRAPHICAL SKETCH.

Harry F. Keller was born in Philadelphia, December 15, 1861, the son of William C. C. and Augusta Maria (Cramer) Keller.

Doctor Keller was educated in the grammar schools of Philadelphia. As a boy he exhibited a keen interest in science and chose chemistry as his special study. He was patient in and devoted to his pursuit. He never tired of experiment, and his youthful demonstrations of chemical facts were keen and convincing. He matriculated at the University of Pennsylvania and the University of Strassburg and attended special courses in the Chemical Laboratories of Professor Fresenius, Wiesbaden. He received the degree of Bachelor of Science from the University of Pennsylvania in 1881, degree of Doctor of Philosophy from the University of Strassburg in 1888, and the degree of Doctor of Science from the University of Pennsylvania in 1915.

As a teacher, in later years, this intuitive power of lucid demonstration and explanation became truly brilliant, winning many to the science he so deeply loved. Due to his love for chemistry he fell naturally into research, where his studies on diacetyl and kindred bodies clearly proved his wonderful grasp of the problems which confronted him. This was true, also, in the domain of mineral chemistry; indeed, in any department of chemical science to which he gave consideration. Those engaged with him in scientific pursuits were quickly impressed with the far-reaching knowledge of the science, which was his, and



HARRY P. KELLER.
1861-1924.

to which he added an astounding understanding of art, literature, mathematics and general science, all of which showed him to be a man of broad and comprehensive vision.

Doctor Keller was the author of "Experiments in General Chemistry" (with Dr. Edgar F. Smith), a book published in 1892. He published numerous papers on chemical and mineralogical subjects, and edited "Greene's Lessons in Chemistry" in 1900; he was also American editor of "Würtz's Modern Chemistry," 1902.

In addition to his duties in a consulting capacity as assayer and chemist for various iron and metallurgical works, Doctor Keller has held the following positions: Assistant in chemistry, 1883–86, instructor in organic chemistry, 1888–90, University of Pennsylvania; professor of chemistry, Michigan College of Mines, 1890–92; professor of chemistry, 1892–1915, head of the department of science, 1908–15, Central High School, Philadelphia; Principal, Germantown High School, 1915 to date of his death.

Doctor Keller was a prominent member of the American Philosophical Society, The Franklin Institute and other societies. He became a member of the Institute in January, 1894, and for thirty years his generous labors contributed materially to the success of the Institute's activities. He became a member of the Committee on Science and the Arts in 1900, elected to the Board of Managers in 1914 and appointed Chairman, Franklin Medal Committee in 1915 when this medal was founded.

In 1892 Doctor Keller married Henrietta M. Hexamer of this city, and is survived by Mrs. Keller, three daughters, Mrs. Hermann Heyl, Mrs. Elmer Peoples, Miss Henrietta I. Keller, and a son, Mr. Harry H. Keller.

Doctor Keller's death occurred on February 5, 1924.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, June 4, 1924.)

HALL OF THE INSTITUTE,
PHILADELPHIA, June 4, 1924.

MR. GEORGE H. BENZON, JR., *in the Chair.*

The following report was presented for first reading:

No. 2822: The Work of Dr. John A. Anderson on Ruling Engines and Seismology.

R. B. OWENS, *Secretary.*

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, June 11, 1924.)

RESIDENT MEMBERS.

JOHN J. ELCOCK, ESQUIRE, Attorney at Law, 1135 Commercial Trust Building, Philadelphia, Pennsylvania.

ERNEST L. HOPPING, ESQUIRE, Mechanical Engineer, 1000 Chestnut Street, Philadelphia, Pennsylvania.

NON-RESIDENT MEMBERS.

LEE DAVIDHEISER, PH.D., Professor of Chemistry, Millersville Normal School, Millersville, Pennsylvania.

JOHN FERGUSON, ESQUIRE, Electrical Engineer, 506 Guaranty Building, Indianapolis, Indiana.

A. NORMAN SHAW, D.Sc., Associate Professor of Physics, McGill University, Montreal, Canada.

CHANGES OF ADDRESS.

MR. FRED H. COLVIN, Editor, *American Machinist*, Tenth Avenue at Thirty-sixth Street, New York City, New York.

DR. ALLERTON S. CUSHMAN, 2201 New York Avenue, N. W., Washington, District of Columbia.

MR. HENRY A. GARDNER, 2201 New York Avenue, N. W., Washington, District of Columbia.

DR. HENRY LEFFMANN, The Coronado, 4 C, N. W. corner Twenty-second and Chestnut Streets, Philadelphia, Pennsylvania.

MR. FRANKLIN P. MCCONNELL, 706 Spruce Street, Philadelphia, Pennsylvania.

COLONEL SAMUEL REBER, Radio Corporation of America, 66 Broad Street, New York City, New York.

REAR-ADMIRAL WILLIAM S. SIMS, U.S.N., 77 Rhode Island Avenue, Newport, Rhode Island.

DR. MAXIMILIAN TOCH, 110 East Forty-second Street, New York City, New York.

C. H. UMSTEAD, ESQUIRE, U. S. N. Hospital, No. 89, Rutland, Massachusetts.

NECROLOGY.

Mr. Frank B. Gilbreth, 68 Eagle Rock Way, Montclair, New Jersey.

Mr. Edward V. McCaffrey, McCaffrey File Company, Philadelphia, Pennsylvania.

LIBRARY NOTES.

PURCHASES.

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GREGORY, R.—Discovery or the Spirit and Service of Science. 1923.

GROGGINS, P. H.—Aniline and Its Derivatives. 1924.

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HILDEBRAND, J. H.—Solubility. 1924.

RUSSELL, B.—The A B C of Atoms. 1923.

SVENSEN, C. L.—Art of Lettering.

VALLERY-RADOT, R.—The Life of Pasteur. 1923.

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Coen Company, Incorporated, Bulletin M. New York City, New York, no date. (From the Company.)

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Columbia University, Barnard College, Announcement, 1924–1925. New York City, New York, 1924. (From the University.)

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Electric Power Equipment Corporation, Bulletin 601, Bennett Lighting Arresters. Philadelphia, Pennsylvania, 1924. (From the Corporation.)

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Link-Belt Company, Book 480, Electric Hoists and Overhead Cranes; Book 550, Portable Loaders. Philadelphia, Pennsylvania, 1923. (From the Company.)

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BOOK REVIEWS.

A TEXT-BOOK OF INORGANIC CHEMISTRY. Edited by J. Newton Friend, D.Sc., Ph.D., F.I.C. Volume II, The Alkali-Metals and Their Congeners, by A. Jamieson Walker, Ph.D. (Heid.), B.A., F.I.C. xvii–379 pages. Philadelphia, J. B. Lippincott Company, 1924.

This work is to appear in ten parts, which are appearing in irregular order, dependent no doubt upon the ability of the special authors to prepare their manuscripts. The plan is for a very comprehensive work, in which the descriptive chemistry will be especially presented. In view of the numerous manuals on physical chemistry, and upon certain phases of it such as colloid chemistry, that department has been given no great amount of space. In the volume in hand the chemistry of well-known alkali-metals is fully considered, and as cognate thereto the chemistry of copper, gold and silver. The use of the word "congeners" in connection with these three heavy metals, two of which have long enjoyed the title "noble," and in physical properties and relation to other elements stand at the extreme of the scale from the true alkali-metals, marks probably the influence of the hypothesis of evolution of the elements from a primordial material, for "congener" carries this signification. The periodic system has acquired dominance in chemistry, but after all the only satisfactory classification is on the tridimensional system. Mention is made in the book that a "cubic" system has been suggested, though no particulars are given in regard to it. The evolution and disintegration of the elements has been recently the subject of an extensive paper by Frank Wigglesworth Clarke. While largely speculative, this paper contains a useful summary of the results of modern research. The scientific world, at least that portion which concerns itself with chemistry and physics, has mostly accepted the hypothesis of transmutability, and hopes for its extension in other directions than those in which it has so far been accomplished. What a boon to science would inure if by some economical method a fairly abundant metal could be converted into platinum. The desire to convert baser metals into gold has been existent through the ages, and has undoubtedly done much to spur men on to metallurgical research, but as a matter of fact, if gold could be produced to-day from even such abundant metals as iron or copper, the process would be of little economic value. The fact that such production was being carried on, even though the secret was with only a few persons, would bring the market value of the metal down to the cost of manufacture plus a moderate profit, and the metal itself has comparative few economic uses, but platinum is unique, and the present vogue of it in jewelry, based simply on its costliness, is a burden to important industries and sciences. The extension of the hypothesis of evolution into the field of chemistry is interesting in view of the desperate attempts of certain bigots to stem the tide of acceptance of it in the field of biology.

The volume in hand constitutes a good manual of the subjects considered, among which is hydrogen and ammonium. In the section devoted to the latter, reference is made to the "so-called ammonium amalgam," but no information is given concerning the preparation of it or the nature of the inflated mass. That a combination of the hypothetical radicle "ammonium" with mercury

may exist momentarily is not impossible, but the visible product is an inflation of mercury with ammonia and hydrogen.

Portions of the work are not yet published; other parts have undergone reprinting. The table on the fly-leaf is seriously defective in that it does not state what volumes are available and the price of each in American money.

HENRY LEFFMANN.

LIGHT AND WORK. A discussion of the quality and quantity of light in relation to effective vision and efficient work. By M. Luckiesh. xvi–296 pages, 70 illustrations, 8vo. D. Van Nostrand Company, New York, 1924. Price, $4.

Dr. Samuel Johnson said that when a nobleman appears as an author his merit should be handsomely acknowledged, and in imitation we may say that when Luckiesh offers a book on any phase of optics we may expect an interesting and valuable volume. Examination of the present work does not disappoint our expectation. It contains a very large amount of useful information, much of which is new and drawn from the author's own investigations and reasonings. The energy we term "light" is generally regarded as one of the most mysterious energies in nature, yet, as a matter of fact, all the phenomena of nature are mysterious, and our views on the subject of light are largely due to the extent to which it puts us in touch with the universe. Color is the basis of beauty in nature. We may be impressed by the vast expense of the sea, of a level plain or of a mountain view, but if there was no color in nature it would seem that we would lose much enjoyment. Yet the philosopher will reason, that if the race had been evolved in a monotone universe, it would have found it as agreeable as the present, because it would have known no better. Luckiesh, by the way, is a firm believer in the influence of environment in determining the character of humanity, and frequently alludes to the fact that man has had a long line of ancestry. In one of the introductory sections he refers specifically to the differences in the nature of the eyes of different species of animals due to the different environments in which they have been evolved. Stating that none but the crudest eye is found beyond the reach of solar radiation, as in caves or at the bottom of the sea, he says,

> "It is against a fortress of such evidence that certain puny men with strange minds which do not seek or recognize truth, are training their antiquated guns loaded with bullets of blind prejudice and powder of ignorance."

Mr. Bryan reading this sentence might say, like Sir Andrew Aguecheek, "That's me, I warrant you." Yet it may be a question whether the sentence is altogether fair, and further, whether such methods of attack by scientists are the best to accomplish victory for freedom in investigation and utterance. Mr. Bryan and his associates are seeking for truth, but they are seeking with a handicap of traditions of ancient times, when scientific methods were scarcely at all developed. They are, moreover, largely influenced emotionally, inasmuch as they are fully convinced that the discarding of the principles on which these views are based will lead to moral collapse. To them the unquestioning acceptance of the text is part of the august process of maintaining the moral order.

That this is the case is well shown by one of Mr. Bryan's latest utterances,

> "The objection to evolution, however, as an explanation of life, is not that it is not true—many things that are false are scarcely deserving of attention. Neither is the ridiculousness of the explanations of evolution, the chief reason for rejecting it, although there is more unintentional humor in these intended explanations than in any intended fun. The principal objection to evolution is that it is highly harmful to those who accept it and attempt to conform their thought to it." (Seven Questions in Dispute.)

The freedom of investigation and utterance so much desired by scientists cannot be secured by the attitude Luckiesh adopts. The validity of the texts on which the opposition is based must be directly attacked, but scientists generally, especially physicists and chemists, are not equipped for this.

However, the book in hand is not intended as a contribution to the dispute on the evolutionary hypothesis. This hypothesis grew out of studies of living organism in their environment and especially in their interactions, and it is the naturalist that can speak with authority. It is fitting, therefore, that the reviewer should turn to the purely scientific features of the text. Here will be found a vast amount of valuable data, expressed, it must be confessed, somewhat dogmatically and sometimes somewhat less concise than could be done, but all the data are of the character of modern contributions to great problems. The work is especially directed to the adaptation of light to human uses. The author, as might be expected, exploits his theory that daylight may often be more expensive than artificial light. Reference is, of course, made principally to factory installation. It is true that windows illuminate only a limited area and in the cold season of the year involve considerable additional heating expense, and in determining "overhead" all such data must be considered. It may not be generally known that Philadelphia has had for more than fifty years a building constructed on a plan that embodies Luckiesh views. The auditorium of the American Academy of Music, long one of the largest auditoriums in the world, is entirely without direct external lighting. It is surrounded by a shell of rooms and lobbies, and must always be lighted by artificial means. For many purposes, the modern artificial lights will suffice, but it may be doubted whether they will serve satisfactorily in all cases. Chemists, the reviewer thinks, would find some difficulty. The examination of minerals, for instance, is best made in daylight. The question, however, is in its infancy. Daylight remains stationary, while improvement in artificial illuminaton advances and the latter is, in the natural course of things, likely to outstrip the former. Probably, however, in domestic life we will not give up looking out of the window even if it is abandoned in the factory.

The book can be commended to all interested in the field.

HENRY LEFFMANN.

THE MODERN SOAP AND DETERGENT INDUSTRY, including Glycerol Manufacture. By Geoffrey Martin, D.Sc., Ph.D., F.I.C. In three volumes. Volume I—The Theory and Practice of Soap-making. 8vo. London, Crosby Lockwood and Son, 1924.

This large and well-printed volume has been arranged on the peculiar and very unwise system of division into sections and paging each section indepen-

dently. The reviewer has not been willing to add up the figures of the pages of the several sections, but the total will be several hundred. Why any author or publisher should at this day abandon the simple and customary method of consecutive paging throughout a book is a puzzle. It has been gratifying to note that, of late years, publishers have been abandoning the practice of paging the title page, contents, preface and certain other more or less introductory matters in Roman numerals. Books are now not infrequently encountered in which the first printed page is, as it ought to be, designated as page one. Paging is a mere mechanical arrangement to facilitate reference by means of an index. Both should be entirely free from classification except by the basic principle of following the numbers of the pages in their proper order and the titles of the index in the arbitrary order of the alphabet of the language in which the book is printed. Even separation of authors' names from subjects seems to be unnecessary. The bookseller who, advertising bargains, catalogued

Mill on Political Economy
" " The Floss

was following the proper method. The volume now under consideration contains no index. This will presumably appear with the third volume and cover the whole work.

The book is very comprehensive. As indicated in the title, it covers specifically soap-making, but a large amount of information is given as to the analytical methods for the many materials used in this important and extensive industry. A great deal of attention is given to the theory of the procedures, and to the general chemistry and physical chemistry of the reactions of soap. A very elaborate and interesting summary is included as to the nature of the changes that take place when soap is dissolved in water. Of the theories that have been proposed to account for the detergent action of soap, the author inclines to the view that this is mainly a colloidal phenomenon. This view has gained support from the fact that colloidal clay has strong detergent properties and has been of late introduced as a substitute for soap.

Manufacturing methods are treated in great detail, a comprehensive and cosmopolitan system of selecting information having been pursued. References are given by year, volume and page, which is highly commendable. The absence of an index is, of course, somewhat of a disadvantage, but the table of contents is in good detail and serves as a temporary substitute. It is needless to say that the work when finished will be a valuable addition to the library of all chemists who are directly or indirectly engaged in the industry to which it relates. It is stated in the preface that the third volume will be mostly devoted to glycerol and will contain information in regard to the processes of fermenting sugars into glycerol, which were so actively developed during the late war. The standard methods of analysis of fats and oils are given in detail, but it seems somewhat astonishing that, in connection with the determination of the volatile fatty acids, only the old Reichert-Meissl method is given. No mention seems to be made of the glycerol-soda process which is now official in the United States, France, Germany and Italy and perhaps other nations. It is much more satisfactory and easier of employment than the procedure given in the book. This is really the British official method, compli-

cated in several ways, and having no advantage in practice over the glycerol-soda method as given in the official publications of the United States.

Undoubtedly the work will find a welcome acceptance, but it is to be hoped that the absurd and inconvenient system of paging will be abandoned and the rational and familiar system adopted. The book is liberally illustrated and the mechanical execution is commendable. HENRY LEFFMANN.

POPULAR RESEARCH NARRATIVES. Collected by the Engineering Foundation of New York City, and published by the Williams and Wilkins Company of Baltimore, 1924. 12mo, 152 pages.

This is a collection of short accounts of important results of research and discovery principally in the field of applied science, especially physics, physical chemistry, chemistry and mechanics, but interesting historical information is not lacking, as is shown by an essay on alchemical symbols. The essays are brief but comprehensive, and told in a form adapted to the general reader, being free from the technicalities of the purely scientific journals. Most of the essays are contributed by experts in the field to which they relate. They have also mostly been published in separate leaflets, and being collected have made a compact and valuable booklet, especially adapted to spread among the people of the country a knowledge of the importance of organized research, both in the pure and applied fields. HENRY LEFFMANN.

EMINENT AMERICAN CHEMISTS. Compiled and edited by D. H. Killeffer, Associate Editor, *Journal of Industrial and Engineering Chemistry*. 4to. Published by the Editor. New York City, 1924. Price, $6.

"There's no art to find the mind's construction in the face," King Duncan says, and the statement is probably true as regards most human beings. In viewing the thirty-three portraits included in this book, we cannot see any evidence of a "chemistry physiognomy," as we might if the collection was one of distinguished judges or ecclesiastics. Perhaps, though, in these instances much of the impression would be made by the garb and not by the countenance. The subjects of the portraits are both living and dead workers in chemistry in this country, but not all are natives. It is a question whether justice has been done to those represented. The pictures are not all well done, and there is no biography of moment. It would seem that a publication of this kind should be a record of the main lines of work of those included and care should be taken that the portraits are of the highest type. Modern photogravure has reached such a degree of finish that there is no excuse for work of a secondary character. The price of the volume seems very high. It would have been better to have made the portraits about half the size and with considerable more information. The book could have been smaller in area and more convenient.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 180, The Influence of the Form of a Wooden Beam on Its Stiffness and Strength—I. Deflection of Beams with Special Reference to Shear Deformations. By J. A. Newlin and G. W. Trayer. 19 pages, illustrations, quarto. Washington, Government Printing Office, 1924.

This publication is one of a series of three reports prepared by the Forest Products Laboratory of the Department of Agriculture for publication by the

National Advisory Committee for Aeronautics. The purpose of the investigation described in this report was to determine to what extent ordinary deflection formulas, which neglect shear deformations, are in error when applied to beams of various sections, and to develop reasonably accurate yet comparatively simple formulas which take into account such deformations.

A great many tests were made to determine the amount of shear deformation for beams of various sections tested over many different spans. As the span over which the beam is tested is increased the error introduced by neglecting shear deformations becomes less, and the values obtained by substituting measured deflections in the ordinary formulas approach more nearly the modulus of elasticity in tension and compression. For short spans, however, the error is considerable, and increases rapidly as the span is reduced.

Two formulas were developed for estimating the magnitude of shear deformations, both of which have been verified by tests. The first assumes the parabolic distribution of shear on a cross-section of a beam and, starting with a differential volume, the distortion due to shear is determined by the ordinary methods of summarizing the work. The second assumes that the deflections due to shear in any two beams of the same length, height, and moment of inertia, which are similarly loaded, are proportional to the summations of the shear stresses on their respective vertical sections. Both formulas check experimental results very closely when the calculations are made with great refinement.

Report No. 181, The Influence of the Form of a Wooden Beam on Its Stiffness and Strength—II. Form Factors and Beams Subjected to Transverse Loading Only. By J. A. Newlin and G. W. Trayer. 18 pages, illustrations, quarto. Washington, Government Printing Office, 1924.

This is the second of a series of three reports prepared by the Forest Products Laboratory for publication by the Committee.

The general aim of the investigation described in this report is the achievement of efficient design in wing beams. The purpose of the tests was to determine factors to apply to the usual beam formula in order that the properties of wood based on tests of rectangular sections might be used as a basis of design for beams of any sections and if practical to develop formulas for determining such factors and to verify them by experiment.

Such factors for various sections have been determined from test by comparing properties of the beam in question to similar properties of matched beams 2 by 2 inches in section. Furthermore, formulas were worked out, more or less empirical in character, which check all of these test values remarkably well.

Report No. 185, The Resistance of Spheres in Wind-tunnels and in Air. By D. L. Bacon and E. G. Reid. 24 pages, illustrations, quarto. Washington, Government Printing Office, 1924.

To supplement the standardization tests now in progress at several laboratories, a broad investigation of the resistance of spheres in wind-tunnels and free air has been carried out by the National Advisory Committee for Aeronautics.

The subject has been classic in aerodynamic research and, in consequence, there is available a great mass of data from previous investigations. This material was given careful consideration in laying out the research, and explanation of practically all the disagreement between former experiments has resulted. A satisfactory confirmation of Reynolds law has been accomplished, the effect of means of support determined, the range of experiment greatly extended by work in the new variable density tunnel, and the effects of turbulence investigated by work in the tunnels and by towing and dropping tests in free air.

It is concluded that the erratic nature of most of the previous work is due to support interference and differing turbulence conditions. While the question of support has been investigated thoroughly, a systematic and comprehensive study of the effects of scale and quality of turbulence will be necessary to complete the problem, as this phase was given only general treatment.

PUBLICATIONS RECEIVED.

Light and Work. A discussion of quality and quantity of light in relation to effective vision and efficient work, by M. Luckiesh. 296 pages, illustrations, plates. New York, D. Van Nostrand Company, 1924. Price, $4.

The Modern Soap and Detergent Industry, Including Glycerol Manufacture. A complete treatise in three volumes on the manufacture of laundry, toilet, pharmaceutical, textile, abrasive, scouring and powdered soaps; also detergent compositions and soap substitutes of all kinds, by Geoffrey Martin. Vol. 1, Theory and Practice of Soap Making. Variously paged, illustrations, plates, 8vo. London, Crosby Lockwood and Company, 1924.

Electrical Measuring Instruments and Supply Meters, by D. J. Bolton. Directly Useful Technical Series. 328 pages, illustrations, plates, 8vo. New York, E. P. Dutton and Company, 1923. Price, $5.

Popular Research Narratives. Fifty five-minute stories of research, invention, or discovery, directly from the "men who did it," pithily told in language for laymen, young and old. 152 pages, 12mo. New York, The Engineering Foundation, 1924.

Eminent American Chemists. A collection of portraits of eminent Americans in the field of chemistry from the earliest days of the Republic to the present, together with short sketches of the work of each. Compiled and edited by D. H. Killeffer, Associate Editor, *Journal of Industrial and Engineering Chemistry.* 33 portraits, quarto. New York, Author, 1924. Price, $6.

The Technical Organization, Its Development and Administration, by John Morris Weiss and Charles Raymond Downs. 197 pages, 12mo. New York, McGraw-Hill Book Company, 1924. Price, $2.50.

Ontario Department of Mines. Thirty-second annual report, part 6, 1923. 104 pages, illustrations, 8vo. Toronto, King's Printer, 1923.

National Advisory Committee for Aeronautics. Technical Notes, No. 187, The Induction Factor Used for Computing the Rolling Moment Due to Ailerons, by Max M. Munk. 4 pages, illustrations, quarto. No. 188, Longitudinal Oscillations of an Airplane, by R. Fuchs and L. Hopf. 40 pages, illustrations, quarto. No. 189, Torsional Strength of Nickel Steel and Duralmin Tubing as Affected by the Ratio of Diameter to Gauge Thickness, by N. S. Otey.

8 pages, illustrations, quarto. No. 190, Comparing the Performance of Geometrically Similar Planes, by Max M. Munk and Edward P. Warner. 27 pages, quarto. No. 191, The Effect of Wind-tunnel Turbulence upon the Forces Measured on Models, by W. L. LePage and J. T. Nichols. 11 pages, illustrations, quarto. No. 192, Note on the Pressure Distribution over the Hull of Elongated Airships with Circular Cross-section, by Max M. Munk. 4 pages, quarto. No. 193, High Altitude Flying, by Paul B. King and Thomas Carroll. 7 pages, quarto. No. 194, A Method of Determining the Dimensions and Horsepower of an Airship for Any Given Performance, by C. P. Burgess. 14 pages, illustrations, quarto. No. 195, On the Distribution of Lift along the Span of an Airfoil with Displaced Ailerons, by Max M. Munk. 7 pages, illustrations, quarto. Washington, Committee, 1924.

U. S. Department of Commerce, Bureau of Standards. Scientific Papers, No. 482, Gravitational Anisotropy in Crystals, by Paul R. Heyl. 18 pages, illustrations, 8vo. Technologic Papers, No. 252, The Nick-bend Test for Wrought Iron, by Henry S. Rawdon and Samuel Epstein. 42 pages, illustrations, 8vo.; No. 253, Standardization of Hosiery Box Dimensions, by Charles W. Schoffstall and E. M. Schenke. 14 pages, illustrations, 8vo.; No. 254, Emissive Tests of Paints for Decreasing or Increasing Heat Radiation from Surfaces, by W. W. Coblentz and C. W. Hughes. 17 pages, 8vo.; No. 255, A Camera for Studying Projectiles in Flight, by H. L. Curtis, W. H. Wadleigh and A. H. Sellman. 14 pages, illustrations, 8vo. Elimination of Waste. Simplified Practice. Range Boilers and Expansion Tanks. 8 pages, illustrations, 8vo. Metal Lath. 6 pages, 8vo. Washington, Government Printing Office, 1924.

Compléments a la Bibliographie des Séries Trigonométriques, par Maurice Lecat. 16 pages, 8vo. Louvain, Author, 1924.

The Effect of a Magnetic Field on the Surface Tension of a Liquid of High Susceptibility. WINIFRED L. ROLTON and R. S. TROOP. (*Proc. Phys. Soc. London,* April 15, 1924.)—To measure the surface tension a vertical capillary tube with a small portion of liquid in its lower and open end is connected to a means of varying the pressure. This is adjusted until the lower meniscus is exactly flat. The pressure in an attached manometer is read. From the dimensions and the pressure the surface tension can be calculated. Strong solutions of ferric chloride and of manganese chloride were investigated on account of their high susceptibility among liquids. When the pressure just made the meniscus plane, the capillary tube being in the narrow air-gap between the pole pieces of an electromagnet, not the least change was observable when a field of 15,800 gausses was called into existence in the gap. If any change in the surface tension is caused by the field, the authors conclude that it amounts to less than .04 per cent. G. F. S.

CURRENT TOPICS.

Accelerated Anode Rays. F. W. ASTON. (*Phil. Mag.*, Feb., 1924.)—When Doctor Aston, through the pages of the journal in which the present paper was published, rendered a report of his splendid work up to the end of 1922, he called attention to the fact "that the difficulties in the way of extending the method of mass-spectrum analysis to other elements lay not so much in the analysis as in the production of their mass-rays. It was particularly desirable that a method should be evolved to give the mass-rays of the metallic elements which form so much the greater number of those not yet analysed. In this connection it is of interest to note that, of all the ordinary non-radio-active non-metallic elements, only one, tellurium, had failed to give a mass-spectrum." In the first attempt positive ions were got by passing an arc between metal electrodes in a vacuum. By a strong electric field these were to be drawn away and guided along the tube of the analyzer, but unfortunately no favorable results were obtained. The hot anode method of Gehrcke and Reichenheim was considered and rejected in favor of the use of a composite anode, which in the hands of G. P. Thomson had furnished good results with certain light elements.

An apparatus was devised that solved the practical problems involved. The anode consists of a steel cylinder encased in a glass tube. In the end of the steel is a cavity filled with a paste made by mixing a halide salt of the element to be examined with, perhaps, sodium, lithium and potassium salts and with powdered graphite, the whole being moistened with a solution of lithium iodide. The presence of the seemingly extraneous elements is valuable on account of the assistance they give in telling when the apparatus is working well and for the bench-marks provided by their lines. The anode rays originating at the surface of the paste are shot toward a cathode with an opening in it through a fall of potential of about 6 or 8 k.v. Having traversed this first cathode, they are further accelerated toward a second cathode through a potential fall two or three times as large as the former. Through a channel in this second cathode the rays pass to make their entrance into the mass spectrograph.

"The principal difficulty in the way of successful working of the method is complete ignorance of the mechanism of the discharge, which is probably very complex. It behaves at times in the most capricious and unaccountable manner. Each time the discharge-tube is altered, or even taken down for cleaning, entirely different results may be obtained. When by good fortune all is well, the arrangement is capable of a surprisingly good performance. Thus, after a particularly favorable setting of the apparatus, six elements were successfully analysed in as many working days. On the other hand, when

dismantling became imperative and it was cleaned and rebuilt—exactly as before, as far as one can tell—no results of any value were obtained during weeks of work." On the other side of the account there is much to be recorded. "In the matter of interpretation, the results of accelerated anode rays are very nearly ideal. The ordinary discharge method gives altogether too many lines due to atoms and molecules other than those under consideration, the hot anode method gives too few, rendering measurement difficult. The new method gives practically no molecular lines at all, and the atomic ones generally present are just about what is required for a satisfactory system of reference, and no more."

The current through the discharge tube was usually from 1 to 1.5 milliamperes, while the potential of the anode ranged from 24 to 30 k.v. The secondary cathode was joined to earth through a kenotron, which was very valuable because of its stabilizing influence.

"The first use to which the new method was put was to obtain accurate mass-measurements of the isotopic constituents of some light elements, the constitution of which had already been determined by other and rougher methods." Many mass-spectra of lithium were taken, under greatly differing conditions of discharge. The two lines corresponding to isotopes of atomic weights, 6 and 7, were inevitable and their relative intensities were always the same. Careful measurements gave for the heavier isotope $7.006 \pm .005$ and for the lighter $6.008 \pm .005$. "The deviation is in the direction expected for a nuclear packing looser than that of helium, but it is in neither case much more than the error of experiment."

Beryllium was once more found to be a simple element, for which two determinations gave 9.003 and 9.001, respectively. The 24 line of magnesium was found but Dempster's 25 and 26 were not detected. Since calcium like magnesium is but a niggardly producer of anode rays its faint 44 line, discovered by Dempster, failed to show itself. The occurrence of first and second order lines of calcium along with the lines of other elements made it possible to measure with accuracy the atomic weight of the chief isotope, 40. "We are therefore faced with the remarkable conclusion that the two isobaric atoms, Ar^{40} and Ca^{40}, probably do not differ in weight by 1/10 per cent., although the structure of their respective nuclei must be different, for one contains two more electrons than the other."

Germanium was found to consist of three isotopes, 70, 72 and 74, of intensities as 2 : 4 : 5. Thus is its atomic weight 72.38 explained. "It will be noticed that Ge^{70} is isobaric with the weakest and heaviest component of zinc discovered by Dempster, and that Ge^{74} is isobaric with the very weak lightest isotope of selenium." Copper gave lines corresponding to isotopes with atomic weights of 63 and 65, with intensities as 2 : 5 : 1. In spite of the atomic weight of strontium being 87.63 only one line and that at 88 could be discerned. Doctor Aston raises the question whether the accepted atomic weight may not be too low. Cobalt showed itself a simple element with one line at 59.

Scandium gave one line at 45, but the faintness of this makes search for companion lines desirable. Manganese gave a single line at 55, while gallium displayed two lines at 69 and 71. Vanadium gave one line, 51, and chromium one at 52. Titanium showed a line at 48, but on one of its spectra a faint ghost at 50 could be detected. Silver very clearly presented two lines of values 107 and 109. "The first of these is slightly brighter. Owing to the weight of accumulated statistical evidence in connection with the relation between odd atomic number and odd atomic weight, and the exceptional trustworthiness of the chemical atomic weight on silver, this result might be described as a foregone conclusion." Yttrium gave no more than one line. This was at 89. Hafnium and zirconium gave negative results as did niobium, molybdenum, cadmium and lead. The author does not regard success with barium as impossible, but it has not yet been achieved.

"If one adds these results to the table given in the previous report of this series it will be seen that the first thirty-nine elements in sequence have been analyzed and, in addition, seven more of higher atomic number, so that the constitution of rather more than half the known elements has been established, in most cases with considerable certainty. The new results given in this paper strengthen the empirical laws observed to hold relating to the connection between atomic number and atomic weight. In the case of the elements of odd atomic number, the rule that they cannot have more than two isotopes still shows no exception, and the law that their atoms should have an odd atomic weight is satisfied."

The author, following Andrade, uses the term "mass-rays" to "cover all swiftly moving particles of matter other than electrons."

G. F. S.

Sun-spots as Magnets and the Periodic Reversal of Their Polarity. GEORGE E. HALE. (*Nature*, Jan. 19, 1924.)—This paper is so interesting that it is difficult to refrain from quoting at too great a length. "Sun-spots have been systematically observed ever since their discovery by Galileo in 1612. Their wide range in size, from single dots on the solar surface to complex groups enormously larger than the earth; their occurrence in zones, about 40° wide on either side of the equator, in which they suddenly appear, only to disappear after a life of days, weeks, or months; their rotation with the sun not uniformly, as though attached to a solid sphere, but at a greater angular velocity near the equator than in higher latitudes; and their systematic variation in number, increasing and decreasing in a period of about eleven years, have long been known. At the maximum many spots can be seen on the sun daily, while near the minimum weeks may elapse without the appearance of a single spot. It will be noticed that following a minimum the spots increase rapidly in number toward the maximum, after which the rate of decrease toward the minimum is more gradual. It may be significant that curves representing the periodic variation in brightness of certain

variable stars are very similar in character. The sun-spot cycle is marked by another characteristic. The first spots of each new cycle appear at relatively high solar latitudes, ranging from about 15° to 40°. As the cycle progresses, the mean latitude of the spots decreases gradually, so that the last spots of the cycle, following the minimum, are near the equator. Moreover, the first spots of the new cycle are sometimes observed as much as two years before the last spots of the old cycle disappear."

Both Faye and Sir John Herschel suggested a vortical structure for sun-spots. Secchi and many others rejected this, and it was not until monochromatic photographs of spots were made in 1908 at Mount Wilson with the red light of the H_α line that "sun-spots were seen to be the centres of vast vortices in the solar atmosphere, . . . and spots were looked upon as solar storms resembling terrestrial tornadoes." For the next advance Sir J. J. Thomson and Zeeman had prepared the way, the former by showing that in a hot, gaseous body like the sun there must be a host of electrified particles. These might give rise to a magnetic field by their rotary motion in the vortex. "In 1896 Zeeman had discovered that when a luminous vapour is observed in a powerful magnetic field most of the lines of its spectrum are separated into three or more components, polarised in distinctive ways." The observations on the Zeeman effect in the sun not only showed that the spots have a magnetic field, but made it possible to tell whether the earthward aspect of the spot was a north or a south pole, and even to state the strength of the magnetic field in the spot and "to determine the angle between the lines of force and the solar surface in all parts of the spot." "Thousands of observations show that all spots contain magnetic fields; that the strength of this field (up to a certain maximum) increases with the diameter of the spot; and that the polarities with a very small percentage of exception follow a definite law which involves the position of the spot on the sun (north or south of the equator) and the number (odd or even) of the sun-spot cycle."

Sun-spots are dark because the gases in them are expanded and made cooler by the centrifugal action in the vortex. It may be that there are vortices in which the gas is not cooled sufficiently to diminish perceptibly its brightness. This thought led to the development of a technique by which invisible sun-spots have been found on Mount Wilson. "The discovery of invisible spots has thus made it possible to study the embryonic and post-mortem stages of visible sun-spots."

From the time of Galileo it has been recognized that sun-spots, like people on a picnic, show a marked tendency to appear in pairs. More recently the eastern and western members of the pair have been found to have opposite magnetic polarity in most cases.

Near the minimum of the sun-spot cycle in 1912 a study was made of the polarity of the spots on the two sides of the equator of the sun. With few exceptions the polarity of the pairs in the northern hemisphere was opposite to that in the southern region. "When

the first spots of the new cycle began to appear in high latitudes near the minimum, we were surprised to find that their polarities were reversed. The southern spots also showed reversed polarities. As the cycle advanced, and hundreds of spots in high latitudes were observed, the same new rule persisted, with a very small percentage of exceptions. A radical change, of the most fundamental character, had apparently occurred. . . . No prediction could safely be made regarding the date of the next reversal of polarities, which might occur either at the maximum or at the minimum of the sun-spot period. Therefore any attempt to formulate a law had to be deferred until after the minimum of 1923." No less than 2110 groups of spots have had their polarity determined. The vast majority of them conform to the polarity that made its appearance just after the 1912 minimum. Toward the close of the cycle a careful watch was maintained for spots presaging the new cycle. The first found displayed a reversal of polarity which has been confirmed by later spots of the new cycle. "The sun-spot period, regarded in the customary way as representing the variation in the number or total area of spots on the sun, irrespective of their magnetic polarity, is about 11.1 years. But if we define the period as the interval between successive appearances of spots of the same magnetic polarity, we thus find it to be twice as long." It should be added that the general magnetic field of the sun is never reversed so far as is known. Furthermore there is no reason to hold that the direction of rotation of the vortices shown in the photographs taken with H_α reverses itself at sun-spot minimum. "It may be remarked that the available evidence seems to point to the existence and origin of the spot vortex (the vortex that gives rise to the magnetic field) beneath the photosphere. The vortex represented by the hydrogen flocculi, shown by spectro-heliograms with the H_α line, is apparently a secondary phenomenon lying at a higher level, where it is quite conceivable that its direction of whirl may be independent of that of the spot vortex below it."

In commenting on this paper Prof. H. F. Newhall, Solar Physics Observatory, Cambridge, calculates the energy of motion with respect to its surroundings that a sun-spot possesses that moves along 4000 km. per day. He computes it to be 2×10^{29} ergs. The magnetic energy of a sun-spot he finds to be about 5×10^{32} ergs, or as much energy as the sun radiates in one-seventh of a second. His opinion of the work done on Mount Wilson is this: "It is scarcely possible to use restrained language in expressing admiration for the superb mass of observational material systematically gathered and discussed by Hale and his associates." G. F. S.

The Bombardment of Elements by α-Particles. E. RUTHERFORD and G. CHADWICK. (*Nature*, March 29, 1924.)—"In previous papers we have shown that hydrogen nuclei are ejected from the elements boron, nitrogen, fluorine, sodium, aluminum, and phosphorus by bombardment with α-particles." These coming from their source

impinged on the element under investigation from which they set free hydrogen nuclei. These nuclei manifested their presence by producing scintillations on a zinc sulphide screen a few centimetres distant. If there were hydrogen nuclei already existing in a free state when they were struck by the α-particles these had a range in air of no more than 30 cm. It was hence necessary to put the screen more than 30 cm. from the bombarded element in order to exclude any effect produced by such already free hydrogen nuclei. Even if the bombarded substance had lost hydrogen nuclei with a range of less than 30 cm., it would have been impossible to detect infallibly their presence by the method used. "To overcome these difficulties we have devised a simple method by which we can observe with certainty the disintegration of an element when the ejected particles have a range of only 7 cm. in air. This method is based on the assumption that the particles of disintegration are emitted in all directions relative to the incident α-rays. A powerful beam of α-rays falls on the material to be examined and the liberated particles are observed at an average angle of 90° to the direction of the incident α-particles. By means of screens it is arranged that no α-particles can fall directly on the zinc sulphide screen." "We have found that in addition to the elements boron, nitrogen, fluorine, sodium, aluminum, and phosphorus, which give H particles of maximum range in the forward direction between 40 and 90 cm., the following give particles of range above 7 cm.: Neon, magnesium, silicon, sulphur, chlorine, argon, and potassium. The numbers of the particles emitted from these elements are small compared with the number from aluminum under the same conditions, varying between 1/3 and 1/20. Neon appeared to give the shortest range, about 16 cm. under our conditions. The other light elements, hydrogen, helium, lithium, carbon, and oxygen, gave no detectable effect beyond 7 cm. It is of interest to note that while carbon and oxygen give no effect, sulphur, also probably a 'pure' element of mass 4 *n*, gives an effect of nearly 1/3 that of aluminum. This shows clearly that the sulphur nucleus is not built up solely of helium nuclei, a conclusion also suggested by its atomic weight of 32.07." G. F. S.

Report to the International Commission for Research on Actinometric Investigations of Solar and Atmospheric Radiation. A. ÅNGSTRÖM. (*Quarterly J. Royal Meteorol. Soc.*, April, 1924.)—For more than a year continuous registrations of the quantity of energy received from sun and sky have been made at Stockholm. The high latitude of this city should be remembered in interpreting the results. Energy was measured in gram-calories. The smallest quantity of energy received upon a square centimetre in a day, two calories, was in January, while in a day of the following June 653 calories came. The mean daily radiation income for December is the smallest, 21, and the total energy received for the entire month is only 662. July has the highest daily and total receipt, 362 and 11,221, respec-

tively. It was possible to segregate the energy received from the sun directly from that coming from the sky. The quantities of energy from the sky vary much less than do the solar contributions. The total coming from the sky in December was 645 calories, the smallest for all the year; for June it was 3390, the maximum for the year. The ratio is 5.2. From the sun alone the least amount received in any month was in December, 17 calories, and the greatest in June, 6420. The ratio of these two quantities is 377. It is further worth noting that in December, when there was little sunshine, thirty-eight times as much energy was received from the sky as from the sun, but in February almost four times as much came from the sun as from the sky. During June, July and August almost 50 per cent. more energy came from sun than from sky.

Other investigations on nocturnal radiation, on the absorption of the lower layers of the atmosphere and on the radiation of different portions of the atmosphere have been made. From these the conclusion is drawn that "the atmosphere is almost perfectly transparent for a certain group of long waves, which penetrates the atmosphere independently of the content of water vapor in the atmosphere and independently of the thickness of the atmosphere. This group of waves constitutes about 25 per cent. of the radiation sent out by a perfectly 'black' surface. The atmosphere, even in very thin layers, absorbs totally a certain group of waves. These waves are almost totally absorbed already in the first 30 metres above the ground at ordinary vapor pressure." This last group constitutes about 50 per cent. of the radiation of a black body near 0° C., and is probably absorbed by the water vapor in the air. G. F. S.

Radium Production in 1922.—One of the most striking of the many striking features of development in mining and metallurgy in recent years is the discovery of large deposits of metals that were long very rare and without particular use. The employment of thorium and cerium compounds in the manufacture of the Welsbach mantle was followed by the discovery of mines yielding the necessary ores in large amount. A somewhat similar course has followed the discovery of helium. Radium ores were scarce when the element was first recognized and the amount present very minute. The value of the material was so great not only from its rarity, but from its unique properties that search was carried out industriously in all accessible regions. Considerable ore of fair quality was found in the United States, but it appears from the advance sheets of the "Mineral Resources of the United States for 1922" that American radium manufacture has been seriously affected by the discoveries in the Belgian Congo. Fasciculus I 27, which consists of pages 557 to 583 of the above-mentioned volume (issued by the U. S. Geological Survey) that in 1921 the radium producer carried stocks so large (a few thimblefuls) that they were obliged to sell at little profit, and they started the year 1922 with over one million dollars tied up in radium

salts and ore. The condition was made worse by competition with the very rich Congo ore. This was discovered in 1913, but the first lot was received at Antwerp in December, 1921. During the year 1922 a standard price of $70 per milligram was maintained. Works now operating in Belgium are said to have a capacity of 3 grams of radium per month in a salt containing about 95 per cent. of radium chloride. The copper deposits in northern Rhodesia are said to be continuous with those of the lower Belgian Congo, and the uranium ores may also be found in British territory. The pamphlet refers to the exploitation of waters exhibiting radio-activity, and states that whatever quality such waters may have at the springs, the bottled samples lose this activity in a few days.

The famous Joachimsthal mines in Bohemia are now part of Czechoslovakia, and the government of that nation is preparing to operate the mines. The total production of radium in the Joachimsthal region from 1911 to 1922, both inclusive, has been 22.3 grams.

H. L.

A Tentative Theory of Light Quanta. LOUIS DE BROGLIE. (*Phil. Mag.*, Feb., 1924.)—The corpuscular theory of light held an honored place in physics until well on into the nineteenth century, such was the weight of Newton's influence. Then there came upon the scene the wave theory with its triumphant explanations of diffraction and interference and the corpuscular theory became a mark for derision. In the last decade or two the quantum theory has been directing thought once more to something not very different from the discarded corpuscular theory. Energy is emitted and absorbed by matter not continuously but in definite tiny chunks or quanta. This conception, originating with Planck, has earned an assured position in prevalent theory by its usefulness. Without it Bohr's atom with all its wonderful ability to unlock the mysteries of the spectrum could not exist. "The photo-electric effect, which is the chief mechanism of energy exchange between radiation and matter," would lack an adequate explanation and our knowledge of specific heats would be much curtailed. The author proposes to himself one of the most essential tasks of modern physics in these words: "I shall in the present paper assume the real existence of light quanta, and try to see how it would be possible to reconcile with it the strong experimental evidence on which was based the wave theory." He assumes that all light quanta are identical in all points save that of velocity, "The light quanta would have velocities of slightly different values, but such that they cannot be discriminated from c (the velocity of light) by any experimental means. It then seems that m_0 (mass at rest) should be at most of the order of 10^{-50} gr." As a result of the application of his conceptions to several phenomena of light, he concludes: "It is then possible to save both the undulatory and the corpuscular characters of light, and, by means of hypotheses suggested by the electromagnetic theory and the correspondence prin-

ciple, to give a plausible explanation of coherence and interference fringes." He recognizes that the reception of his ideas would bring with it the necessity of framing a new electromagnetic theory that should align itself with the conception of "all the real energy of the fields being probably of a corpuscular fine-grained structure."

G. F. S.

A Method of Drawing Metallic Filaments. G. F. TAYLOR. (*Phys. Rev.*, May, 1924.)—A century ago Wollaston made platinum wire with a diameter of .000075 cm. by drawing down a silver wire with a platinum core and by later dissolving the silver in acid. The present method was developed to meet the needs of the Bureau of Plant Industry for thermocouples and resistance thermometers of very small sizes, and bears a certain resemblance to Wollaston's method. The metal to be drawn is enclosed in a tube of glass that softens between the melting and boiling points of the metal and that does not combine with the metal. A method of manipulation is given by which the metal is freed of oxide. A copper rod with a series of holes perpendicular to its length is heated at one end by a flame. A glass rod with the contained metal is pushed into a hole with the suitable temperature. From the distant end of the hole the tube is drawn away with forceps, and, of course, the metal is drawn out with the glass. The size of the resulting filament depends on the thickness of the walls of the tube and on the rate of feeding in and of withdrawal. These metals may be drawn in the manner described, Pb, Sb, Bi, Sn, Cd, Ga, Tl, Cu, Ag, Au, Fe, In, Al, and alloys of the same metals. Special glasses are required with some metals as well as certain tricks of manipulation. Aluminum was drawn in a tube made of its own borate. In general hydrofluoric acid was used to dissolve the glass sheath of the filament.

Wires thus prepared have bright metallic surfaces. When their diameters are no more than .0001 cm. they can be seen owing to irradiation. The size of much smaller wires can be calculated from their electrical resistances, on the assumption that the specific resistance has not been changed by drawing. One filament of antimony had a resistance of 125,000 ohms per cm., and was calculated to have a diameter of .00002 cm., No. 92 B. and S. gauge.

Such wires have been employed for resistance thermometers where a high resistance in a short length is valuable. Use for hair lines in eyepieces is also suggested. G. F. S.

Electrolytic Preparation of Metanilic Acid and Its Commercial Possibilities.—Paraminobenzenesulphonic acid has been long a familiar synthetic under the more convenient name of sulphanilic acid. Arthur K. Doolittle has studied a method of preparing the meta-form by means of electrolysis. The meta-form has applications in the manufacture of synthetic dyes, of which metanil yellow has the widest application. Very large quantities of this dye are manu-

factured, although it is somewhat poisonous. The acid is at present made by reducing metanitrobenzenesulphonic acid. Doolittle gives details of this method and also the reactions involved. Experiment showed that no appreciable transformation occurred by the electrolytic method at room temperature, but the yield increases as the temperature rises. Increase of current density increases yield, but increase in the concentration of the depolarizer does not. Difficulty was found in determining the amount of acid produced, on account of the slow action in titrating. A method of duplicate titration was devised which to a great extent overcame this difficulty, but the results of the investigation showed that no satisfactory large scale procedure can be devised on the data obtained. The paper was presented at the forty-fifth general meeting of the American Electrochemical Society, at Philadelphia, April, 1924. H. L.

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